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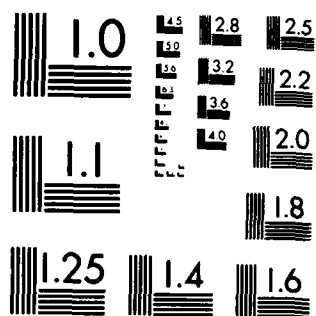
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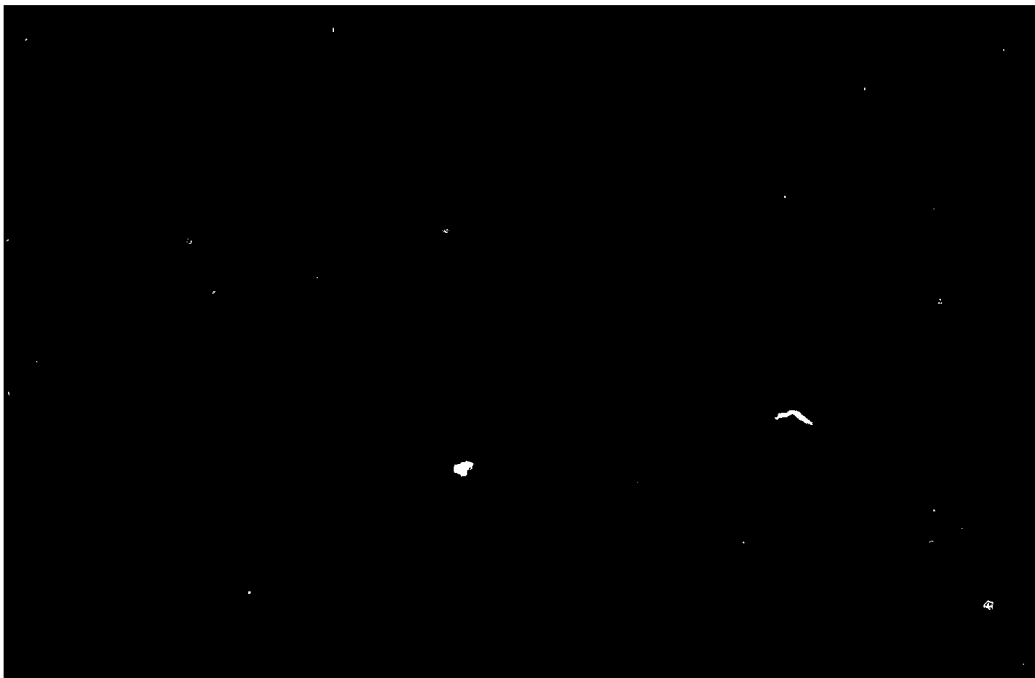
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This report provides seven appendixes which contain detailed information on certain specific development areas in support of the Automated M55 Detonator Production Equipment Program (Volume I). The seven appendixes are as follows:		
<ul style="list-style-type: none"> • High Rate Prototype Concept and Pilot Line Design • M55 Detonator Iowa Loader Characterization Effort 		
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- Operational Shield Test for X4 Loader
- Evaluation of Inspection Equipment Design "Lessons Learned"
- Metering Accuracy Iowa Ball vs Chamlee
- Detonator Seal and Dry System
- Improved Aspiration System



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APPENDIX A

HIGH RATE PROTOTYPE CONCEPT
AND PILOT LINE DESIGN

SYSTEM DESCRIPTION

Prototype System

The long-term objective of this program is to develop an automatic line to manufacture and inspect detonators at a rate of 1200 parts per minute (ppm). This section describes the concept for the prototype line (figs. A1 and A2). The next section describes the components of a pilot line which will demonstrate the operation of all system elements of the prototype line at a rate of 1,200 units per minute while producing 100 detonators per minute. The third section provides a detailed description of the pilot line subassemblies, while the fourth section provides inspection techniques. The concept for the prototype line uses the newest and most successful technology in munition manufacturing. Manufacturing operations will be performed by tooling mounted on continuously rotating turrets. Detonator cups will be transported from one turret to the next by carriers on a precision roller chain. Once a cup is loaded into a carrier on the chain, it will not be released until the detonator is completed. Perfect alignment will be achieved at every work station by self-centering collets on the chain.

Three auxiliary powder-transport systems, synchronized with the fill turrets, will maintain a powder supply from the magazine to the assembly line.

The prototype detonator production line will consist of 18 turrets joined by a roller chain to transport detonators through the machine. Major systems of auxiliary equipment will include the three powder-supply systems, the detonator-drying oven, and the control center.

All functions required for assembly of the M55 detonator will be performed on rotary turrets; therefore, the system will operate continuously rather than intermittently.

The prototype system functions basically the same as the pilot line. The major differences are that in the prototype a separate and individual powder-supply turret is provided for each type of powder, and an identical tooling module is provided for each of the 24 stations on each turret. Two vibratory-bowl cup-feeder inputs are required to maintain the 1200 ppm output of the prototype; whereas, only one is required for the 100 ppm output of the pilot line. The 45-deg crimp, the 90-deg crimp, and the lacquer application operations are performed on separate turrets, and each detonator cup makes only one pass through the prototype system; whereas, a cup in the pilot line is recirculated 6 1/2 times before it is completed. A greater number of brushing and aspirating actions will be incorporated into the prototype design due to the longer chain, the individual powder-supply turrets, and the general physical increase in equipment size.

The philosophy of the design of the pilot line is such that a successful demonstration of detonator production will ensure the safe and successful performance of the prototype line; the functional principles of operation of both lines are identical. As such, all the functions described for the pilot line will be duplicated in the prototype line. Where the pilot line will have two functional

modules for each operation on a particular turret, the prototype line will have a complete turret dedicated to that operation with the modules on the turret performing the same operation.

Pilot System

The near-term objective of the program is to design and build a pilot line to manufacture and inspect detonators at a rate of 100 ppm, while demonstrating the capability of producing at a rate of 1200 ppm when applied to the future prototype line.

A continuous-motion rotating-turret concept was chosen for the detonator line because of the many advantages of this system. An obvious design concept which was considered was to build the frame, drive, chain, all turrets, etc., of the entire proposed prototype line (18 turrets), but provide only two tool stations on each turret to produce 100 ppm. This approach would provide a very complete demonstration of the production techniques, but would also be very expensive. Because of this inherent high cost, this approach was not pursued.

An approach was then taken where a scaled down machine configuration would demonstrate all assembly and inspection operations at a rate of 1200 cycles per minute, while producing 100 detonators per minute (figs. A-3 and A-4). This line requires only six turrets while the ultimate prototype line will require 18 turrets. This reduction is made possible by using each turret for more than one operation.

One powder-supply turret will be designed to load all three required powders into the appropriate cups of the powder-transfer conveyor. A second turret will be capable of metering the three powders into the cups in the proper sequence, and a third turret will handle all three consolidations in the proper sequence.

In the following paragraphs, the sequence of operation is described on one typical detonator assembly as it travels through the system (fig. A-4.). The cup-feed system will deliver an empty detonator cup to a starwheel, which will transfer the cup to turret 1, where it will be pressed into a chain carrier in line with station 1 on that turret. Moving at a rate of 1200 carriers per minute, the chain will transport this cup to turret 2, where it will be in line with station 1 of that turret.

Station 1 of turret 3 will contain a metered charge of NOL-130 ready for transfer into the cup. The transfer will occur at the interface of turrets 2 and 3, with station 1 of both turrets being aligned at that point. Turret 3, the powder-filling turret, will be resupplied with powder by turret 4. A three-section supply arrangement is provided on turret 4, and the powder-transfer conveyor belt system will deliver refill supplies of each powder to the corresponding powder hoppers on turret 3.

The NOL-130 powder will then be transferred into the cup and will be consolidated by the pressing tools of station 1 on turret 2. The cup will then be transported by the chain to turret 5.

Tooling at station 1 will brush and remove any loose powder. The cup will continue to turret 6, in line with station 1, which will be an empty station with no tooling and no work performed.

The chain will return the partly completed detonator to turret 1 where it will begin a second trip around the turrets. The length of the chain between turret 6 and turret 1 will be one carrier pitch longer than a multiple of 24 carriers, so that on this second pass through the system, the cup will be in line with station 2 on the turrets. Turret 3 will deposit lead azide powder, turret 2 will consolidate it, turret 5 will brush and aspirate, and no operations will be performed on turret 6.

The chain will again return the cup to turret 1, this time in line with station 3. The cup will travel through the system again, receiving a metered charge of RDX. This powder will be consolidated, brushed, and aspirated, and the detonator will then start another pass, in line with station 4 on all turrets.

No operations will occur until the cup reaches turret 5 where the foil disc will be installed at station 4. At station 4 of turret 6, the first or 45-deg, crimp will be formed. The cup will pass around again, in line with station 5 on each turret. No action will occur except on turret 6 where the 90-deg crimp will be formed.

On the following trip around the chain path, the cup will be in line with station 6 of the turrets. The only activity is at turret 6 where sealant lacquer will be applied. On the next and last trip through the system, a puck or holder will be fed through a starwheel to station 7 of turret 6. The detonator will be pressed into this puck and the puck/detonator assembly will be removed from the turret and placed on the conveyor to the drier.

All the required automatic inspections will be performed as the detonator progresses through the system, and if a detonator is found defective, it will be discharged at the reject station.

The foregoing description relates to a cup placed initially in line with station 1. After 12 chain-carrier pitches, another cup will be placed in the chain in line with station 13 which is 189 deg away from station 1 on turret 1. This cup will proceed through the system, aligning in sequence with tooling at stations 13 through 19. These tools are 180 deg opposite the first set of tools on the same turrets. An empty cup will be loaded into every twelfth carrier on the chain.

Each turret will include 24 tool positions but only two sets of each item of required tooling. The turret diameter (D1 of fig. A-4) will be approximately 23 inches. The diameter (D2) of the starwheels for loading cups or pucks will be one-half D1 or about 11 1/2 inches. The circumferential velocity of the starwheel will exactly match the circumferential velocity of the turret. The starwheel with only one transfer pocket feeds two cups every revolution of the turret.

The chain is moving at a rate of 1200 carriers per minute, with an operation being performed on every twelfth carrier. Production of detonators will, therefore, be 1/12 of 1200 or 100 detonators per minute.

The operation of this pilot system, although somewhat difficult to describe, is actually very simple. The cups will be automatically loaded into the designated carriers of the continuously running chain and transported through the system seven times. The appropriate tool stations on the turrets will automatically perform the required operations. The completed detonators, in carrier pucks, will be automatically delivered from turret 6 at a rate of 1200 ppm, while actually producing 100 ppm.

This pilot line will completely prove every element of the prototype production line. The chain, the turrets, every tool station, and every automatic inspection device will be usable on the ultimate prototype line. Furthermore, all these devices will be operating on the pilot line at the rate necessary for production of 1200 detonators per minute. After the pilot line has been successfully tested, a prototype line can be constructed, using the same devices applied to a complete line with more turrets and with 24 sets of tools on each turret.

All development problems associated with the automating of detonator production will be solved on the pilot line, and the demonstrations will prove that the problems have been solved.

Pilot Line

Cup-Load Turret

The cup load turret, (figs. A-3 and A-4), is located on the left side of the pilot line and performs the initial loading of the cup into the system. The turret consists of a welded square tube frame mounted on a commercial channel-iron base. A thick plate is mounted on the frame to support the turret which is mounted on bearings and held upright by three vertical pillars and a triangular top plate.

A starwheel mechanism, mounted on the left-hand side of the turret, is fed detonator cups from a vibratory feeder and belt-drive transfer plate mounted on a smaller table weldment to the left of the starwheel and turret. The turret is driven from a horizontal drive shaft coupled in line with that of the adjacent station. The drive shafts are connected in line at each module and driven by a 15 horsepower explosionproof variable-speed electric motor.

Power to the turret is transmitted from the horizontal drive shaft by pulleys and a timing belt to a gearbox mounted to the end of the vertical turret shaft. The starwheel is driven from a gearbox on the turret shaft through a right-angle drive, timing belt, and pulleys.

The empty cups are placed in the bowl of the vibratory feeder, which orients them vertically, open end up, and passes them down a track into the transfer plate. A pair of horizontally mounted miniature V belts, driven by a small independent motor, transfers the cups from the feeder, across the plate, in tracks, to the starwheel. Electronic sensors monitor parts flow at this point.

As the turret revolves, the starwheel picks up a cup from the transfer plate in a specially designed nest and revolves the nest in the horizontal plane in synchronization with another nest mounted on a vertical module on the

revolving turret. The cup is plowed out of the starwheel into the turret by means of a fixed plow and guides. An endless chain with special spring-loaded carriers wraps around the turret on a lower plane than that of the cup input.

The turret module is equipped with two vertically mounted rams on the same centerline as that of the nested cup and chain carrier (one above and one below). The rams are driven toward the cup by two fixed cams.

As the cup is plowed out of the starwheel and into the turret module, it rides over a fixed deadplate or transfer plate. By the time the cup, still held in the turret module, reaches the termination point of the transfer carrier, it has been lifted into a locating device under the cup nest, and the upper ram has been lowered to an initial level, enabling the punch to enter the cup just clearing the bottom surface. As the cup leaves the end of the transfer plate, the upper ram is cammed down hard, guiding the cup into the mouth of the pre-located carrier and down to the required nesting position. The upper ram is then raised, in advance of the lower ram being retracted from the carrier, allowing the carrier to spring back down to its normal position in the chain and to ride out of engagement with the sprocket on the initial turret.

To determine if the cup is placed correctly in the open-end-up position in the carrier, a horizontal plate or "flag" is mounted on the lower ram, projecting radially upward. At the lowest point of travel of the upper ram, a variable inductance transformer (VIT) is mounted so as to take a reading from the flag on the lower ram. If the cup is inserted correctly, the sensor will read the flag correctly and transmit an "accept" signal to an encoder on the top plate of the turret. If the cup is upside down, the lower spring-loaded ram will be depressed by the cup, causing an incorrect readout from the sensor.

Another flag will be mounted in a fixed position on the turret in a different angular location from that of the nest, at the "accept" level. This flag acts through the VIT as a safety calibrating device.

For the pilot model only, two modules with identical rams and nests will be mounted 180 deg apart on the turret with special sprocket segments to support the chain. These two modules will load 50 cups per minute each, for a total of 100 cups per minute. The prototype turret will be capable of mounting 24 modules for the prototype design and will load 1200 cups per minute.

Powder-Supply Turret

The powder-supply turrets are safely located in concrete-walled magazine rooms separate from the main equipment. A conductive rubber and wire-cored powder-supply belt runs from each turret through small openings in the concrete barrier wall to its associated powder-metering turret on the main equipment.

Both the powder-supply turret and the powder-metering turrets are equipped with pulley grooves for the belt, while drive pins engage pockets in the belts to maintain belt drive synchronization. The powder-carrying cup-shaped depressions in the top of the belt are always in alignment with the appropriate cavities in the six equally spaced rotary metering shafts immediately above. These metering shafts are similar in design to those of the powder-metering turret, except that their metering cavities are larger and no adjustment of

powder volume is necessary because they are used on a computer-controlled demand basis. The metering funnels are small flanged conductive nylatron bushings that fit into holes in the bottom of a large circular powder-supply groove at the top of the dial plate, while light sealing pressure against the metering shafts is provided by O-rings. The paddle trails on a hinge within the powder-supply groove without touching the walls or bottom. It is suspended by a knife-edge bearing support. The purpose of this paddle is:

- To evenly distribute the powder in the groove that rotates beneath; otherwise, a void would appear in the powder because the powder is locally drawn into the metering funnels

- To function as a powder-demand detector

The top of the paddle carries a flag, and as the trailing angle approaches vertical, due to the reduction of the powder level, the flag interrupts a stationary photocell beam fixed in its path. The signal generated is used to operate a warning light for manual refill or, if desired, an automatic bulk refill system.

The paddle is not stationary; the relative velocity between it and the rotating powder at 55 rpm would be unacceptably high. Therefore, a planetary gear system is incorporated which produces a safe relative velocity between paddle and powder. A ring gear fixed to the dial plate is furnished with tracks for cam followers. These cam followers locate and support a planetary carrier ring, allowing it to rotate freely around the turret vertical axis. A planetary gear attached to the planetary carrier ring makes possible a reduction of the carrier ring speed to approximately 28 rpm; the resulting speed differential between the paddle and the powder groove is about 22 rpm or approximately 1.9 ft/s linear velocity. The carrier ring acts as a shroud to completely cover the bearing and gears; a groove labyrinth on its periphery also helps to maintain a sanitary condition around these components. A stationary sun gear fixed to its adapter completes the necessary gear train.

As a precaution to prevent powder spillage from the belt cup depressions due to vibration or windage during transfer, a cover belt runs immediately above, in position to maintain a light pressure contact with the powder transfer belt as it leaves the powder-supply turret. Both belts are supported by pairs of freely rotating nylatron-flanged pulleys spaced approximately every 6 inches along a section of I-beam track that connects the powder-supply turret and powder-metering turret. Synchronization of the cover belt with the powder-supply belt is unnecessary, although the speeds of both belts are the same. The lower belt is driven by a gear/belt arrangement from the top of the cup-load turret shaft to the pulley wheel shaft on the powder-metering turret. This pulley wheel assembly is identical to that on the powder-supply turret except that the idler shaft is extended and carries the drive-gear belt pulley.

The dial plate is keyed to the main turret shaft and is retained by a nut. Sealed flanged bearings located at the top and bottom of the shaft are mounted in a triangular top plate and rectangular baseplate. The baseplate, support pillars, frame weldment, gearbox, and drive shaft details are similar to those of the main equipment.

The metering station modules are located within radial slots on the underside of the dial plate and are retained by two bolts which secure the metering block. The metering shaft operates in a semirotary 180-deg movement in flanged nylatron bearings, and is driven by a spur gear by means of a gear quadrant. As the gear ratio is 3:1, the gear quadrant angular movement is only 60 deg; this movement is provided by the cam follower as it rotates around the stationary barrel cam. Supported on its pedestal, the cam also serves as a rotary valve design to perform the alternate vacuum and pressure functions necessary to fluidize, meter, and transfer powder into the transfer belt at the appropriate time. Ports in the valve slip ring are connected by means of plastic tubing to the dial plate and then to the metering block. Static and dynamic seals are provided to prevent vacuum loss; the porous filter is an effective barrier to the ingress of any powder to these air channels. The rotating valve slip ring is loaded against the stationary cam/valve by springs and is forced to rotate with the dial plate by a key.

A solenoid air valve is incorporated in the air-supply line to the cam/valve which functions not only as a fail-safe powder charge inhibitor, but also provides a short, sharp pneumatic pulse to remove the powder charge from the metering shaft cavity without the "dusting" usually associated with a larger flow of air.

The description of the powder-supply turret for the prototype line basically applies to the corresponding turret of the pilot line. However, as only one turret is employed on the pilot line for all three powders, the paddle and planetary gear system is not required, and the continuous powder-fill groove in the dial plate is compartmentalized to separate the different powders. These compartments will be filled manually on the pilot line, and the running time between refills will be determined by the amount of powder that may be stored in the magazine in accordance with safety requirements.

Angular spacing of the station modules also differs on the pilot line turret with a group of three stations adjacent to each other on opposite sides of the dial plate.

Safety Loading Doors, Pilot Line

The pilot line has no provision for automatic inspection of the three powder levels in the single powder-supply turret; the levels are inspected visually. To provide a high degree of safety while manual loading and resupply take place, an interlocking safety door system is employed. Four 5/8-inch-thick steel plates are sandwiched together with bolts and spacers and form part of the inside of the barricade wall of the powder magazine. The plates have door openings, and doors slide up and down the cavity between plates formed by a spacer slightly wider than the door thickness. Each door is composed of a four-ply laminate of 1/4-inch-thick lexan and is raised and lowered within the door cavity by chains and counterweights similar to those used in a sash-cord window. The chains are operated by a sprocket on shafts passing through nylatron bushings in the plates and are connected to handwheels on the outside of the magazine. On the operator's side below the outside door, a shaft is mounted which slides in sealed, linear ball bushings. The shaft carries a conductive rubber pouring cup at one end and a bolt handle at the other end. The handle

slides axially along a slot in the ball bushing housing and the shaft cannot turn or pour powder until the handle has been rotated approximately 95 deg to the end of its 9-inch linear travel.

A small latch located below the outside door is lightly spring loaded upward to engage in a mating recess underneath the shaft. This latch is moved down, releasing the shaft, only when the outside door is fully down.

An interlock shuttle moves back and forth between the inner and outer doors; it is arranged so that only one door at a time can be raised. This ensures that there will be at least one closed safety door between the operator and the magazine interior at all times. A small pneumatic vibrator is mounted outside on a short vertical stem which contacts the bolt handle as it reaches the end of its final "pour" position. The vibration imparted to the shaft, and therefore to the cup, ensures that all the powder in the pouring cup is fully transferred to the compartments in the powder-fill turret ring groove.

Metering Turret/Supply Turret, Alternate Design

In response to a request from Picatinny Arsenal personnel to study alternate and less complex means of powder supply to the metering turrets, an alternate concept was evolved incorporating the following requirements:

- Total elimination of an extra powder supply turret for each of the three powders
- Elimination of the powder supply belt, cover belt, cover belt, and associated drive system components
- Elimination of the separate powder magazine barricade construction
- Elimination of height inspection of powder in the 24 powder funnels on each of the three metering turrets
- Total enclosure of all powder from main supply to metering point
- Minimization of equipment damage in the event of accidental main powder supply explosion
- Maximum safety through roof-vented explosion shield pipe around main powder supply
- Smaller powder supply volume required for any given number of detonators produced
- Stationary agitator blades may be employed, eliminating the need for a planetary gear system for this function

Technical Principle

The principle of powder transport through small-bore tubing has been successfully proved with many types of powders. However, the fine and clinging nature of NOL 130 renders its promotion through such tubing very difficult by gravitational, centrifugal, or vibratory means, because of the tendency of self-compaction within the tubing bore. Following the principle used in the feasibility bench model for powder fluidization by alternate vacuum/pressure pulses, a simple test was conducted to ascertain whether NOL 130 powder simulant could reasonably be expected to be transferred through small-bore tubing by this means. The apparent success of this preliminary test resulted in the design of the alternate metering turret incorporating the tube-feed principle and the construction of a jury rig to establish the feasibility of the system under simulated turret conditions.

Metering Turret Description, Alternate Design

The turret consists of a vertical shaft running in flanged cartridge bearings mounted at the bottom and the top of a stationary outer housing attached at its base to the table top of the machine. The shaft is driven by the main drive through a gear reducer mounted under the table, the general design closely following that of the other turrets in the system.

A main powder supply hopper, mounted at the top of the vertical shaft, is peripherally fitted with small-bore nylon tubes that connect the hopper interior to each metering mechanism. These metering mechanisms are similar to the previous metering design, but the powder supply funnels are replaced with small spring-loaded sleeves connected to the end of each tube. Therefore, the powder is thus totally enclosed from the main supply to the point of the metered charge dump into the die funnel of the adjacent consolidation turret, and the powder level inspection previously needed in this area is no longer required.

The stationary cam operates the metering shaft and incorporates the alternate vacuum/air pressure as before, but an additional valve gallery is provided as a separate means of fluidizing the powder in the main hopper to prevent bridging and voids in the powder. The pneumatic path for this fluidizing is shown connecting the inner valve gallery through O-ring seals to the center of the main turret shaft, and then up to a chamber underneath a core fixed to the bottom of the powder supply hopper. This chamber is provided with a porous filter ring, and a series of slots in the base of the core allows fluidizing to take place close to where the powder is drawn from the hopper. The powder is transmitted through the tubing by the alternate on/off pulses of vacuum at the metering shaft cavity.

As the design utilizes a powder supply rotating close to the center of the turret, the peripheral speed of the powder allows a stationary paddle to safely perform further mixing in the hopper as an alternate and simpler previous design. The powder supply hopper is surrounded by a thick tubular detonation exhaust shield extending through the roof of the building as a means of minimizing the effects to personnel and equipment of any accidental explosion of the main powder supply. Continuous inspection of the powder supply height is also made by optical means within the exhaust tube, and refill of the powder supply can be performed without stopping the turret.

A powder hopper design for the pilot line is shown in figure A-5, all other features of the turret remain the same. Three separate powders are contained in concentric ring grooves in the hopper, all of which may possibly be refilled without stopping the turret. The number of detonators manufactured between refills is entirely dependent on the bulk powder safety requirement standards established. Although no provision is made for pneumatic fluidizing of the powders on this pilot line hopper, a stationary blade is utilized to prevent bridging and voids in the powder. The low peripheral speed of the rotating powder relative to the blade is considered well within acceptable limits.

Based upon the results of tests conducted and the simplicity of design, the alternate metering/supply turret was considered the preferred design for future efforts.

Consolidation Turret Assembly

The consolidation turret with the top punch and the lower punch in their final consolidation positions is shown in figure A-6. Fast approach strokes are provided by the side-mounted cam followers working in the stationary top and bottom barrel cams, while the yoke-mounted cam follower on the centerline of the top punch is operated by a separate and adjustable cam section.

This adjustable cam section is provided on the pilot line consolidation turret so that if any changes in the final slope and dwell characteristics are found necessary, this cam section may be readily altered rather than undertaking an expensive rework or replacement of the entire barrel cam. At the area around the barrel cam where the operation of the cam section occurs, the barrel cam track widens slightly, so that it does not interfere with the operation of the yoke cam follower. The adjustable compression die spring, already preloaded to the required consolidation pressure by internal adjusting screws, is compressed approximately 0.030 inch more at the final consolidation position, as shown by the cross-stop pin of the inner ram lifted 0.030 inch off its normal spring-seated position. The inner ram carries an adjustable flag operating in conjunction with a stationary variable inductance transformer to provide an accurate readout of consolidation depth.

The chain carrier in the raised position is located firmly and accurately in the tapered set at the bottom of the powder funnel. The detonator cup rim is seated in a small register in the center of the tapered seat, and is raised and held in position by the lower anvil punch. A cylindrical, resilient, conductive rubber bush surrounding the lower anvil punch provides the axial spring pressure to hold the carrier accurately in its powder-funnel location.

Accumulative manufacturing tolerances preclude the possibility of providing the alignment requirements of the top punch and powder funnel by accuracy of machining alone, so the powder funnel is accurately located with reference to the top punch by a dial-indicator fixture. The two dial indicators on the fixture are first zeroed on the punch, then the powder funnel is adjusted by means of setscrews to provide equal readings and locked in the position. Positive, accurate alignment of punch and powder funnel can be performed either on a bench off the turret or on the turret.

The consolidation of the detonator powder charge takes place on a turret separate from the metering turret, therefore, minimizing the risk of propagating a detonation from the consolidation turret to the metering turret. Nevertheless, because a 3-inch chordal space exists between each station module, a thick steel barrier is securely anchored between each module to even further minimize the propagation risk. The radial barriers between each of the station modules have a peripheral extension which forms an L shape to the barrier. The length of this L extension exceeds the length of each space between a set of stationary radial barrier plates with top and bottom covers forming individual chambers, with this assembly mounted near the rotating barriers. Any detonation flash during consolidation would be limited, therefore, to only one module, considerably reducing the risk of propagating any detonation that may occur.

Seal-Insertion Station

The seal-insertion station is on the same turret as the brushing and aspirating station. The major components of the seal-insertion station are as follows:

- Reel unwind
- Feed mechanism and scrap cutter
- Blanking tools
- Cup support and motion
- Stripping and insertion
- Die setting
- Safeguards

The seal-insertion station mechanism blanks a sealing disc from an aluminum strip and inserts the disc into a filled, cleaned cup in one continuous motion. The 0.003-inch-thick strip is supplied in a coil on an aluminum core; a 5-inch-outer-diameter reel provides enough material for 10 hours of continuous operation.

The reel is fastened to an unwind stand and positively held by a quick-release, quarter-turn thumbscrew. The stand, mounted at an angle on the turret radius, is equipped with an adjustable braking system for maintaining proper web tension.

The strip runs under the idler and over a turnbar which changes the direction of strip travel from linear to radial. This portion of the strip path (after the idler and beyond the turnbar) is made up of two strands located in parallel horizontal planes so that the angle between the strands remains constant, unaffected by variations of coil diameter.

Leaving the turnbar, the strip runs through the die set, where it is blanked. Two pinch rollers then engage the perforated strip, transmitting an

indexing motion to the foil. The downstroke of the ram actuates a gear-and-ratchet assembly which provides the intermittent power required to index the pinch rolls. The same downstroke also actuates a shear, located at the exit of the feed rolls, which acts as a scrap cutter. A collecting trough under the cutter receives the scrap and funnels it to a vacuum removal line.

The blanking tool set consists of a conventional die and a special hollow punch very similar to the tool set used in the machine currently employed to produce nonelectric detonators. The hollow punch houses a flanged, spring-loaded (upper spring) stripper pin. The die is mounted on a special tool plate, while the punch is attached to the upper ram. After blanking, the punch assembly continues its down motion with the disc held against its face by the force of downward acceleration. At one point, about 1/4 inch from the edge of the cup, the stripper pin is triggered by a ram-mounted rocker arm making contact with an adjustable stop mounted on the housing. In the process, the rocker arm overcomes the (lower) retaining spring, whose purpose is to keep the stripper face flush with the punch face. From this point on, the stripper travels at twice the punch velocity. The disc is therefore pushed into the cup by the stripper pin, although the punch never reaches the edge of the cup. During the very last portion of the downstroke, the preload (upper) spring is compressed, ensuring that the disc is firmly seated on top of the charges while limiting the pressure to a preset level.

To provide accurate location and cup support for the operation described above, the lower ram is equipped with a long pin and an outer, polyurethane spring. The spring pushes the sliding cup holder of the carrier chain upward into the plate underneath the blanking die. Because the nose portion of the cup holder is tapered, the upward thrust of the spring accurately positions the holder. As the lower ram continues its upward motion, the spring is compressed while the center pin rises until it butts against the cup bottom and supports it during the disc-insertion cycle.

Because of the nature of the operation, concentricity of the die and punch is particularly important. Therefore, a special fixture has been designed to accurately locate the punch relative to the die. The fixture consists of a center block, two dial indicators, and a calibrating plug. The center block, on which the disc indicators are radially mounted, is accurately centered on the die by means of a dowel pin protruding from its lower face. The pin acts as a calibrating plug which fits snugly into a very accurately aligned, concentric bore. The plug diameter is larger than the die bore diameter, but a portion of the plug is necked down to the exact outer diameter of the punch. The tips of the two dial indicators contact this portion of the plug. When the plug is correctly aligned, the dials are set to zero.

After the dials are zeroed, the calibrating plug is removed, and the punch is lowered into the bore until its lower end contacts the dial indicator tips. The punch hold-down screws on the ram assembly are then loosened to allow lateral movement of the punch. By shifting the punch until both indicators read zero, the punch is exactly aligned with the calibrating plug and, therefore, with the die.

As a means of monitoring proper disc blanking, the presence of the perforated strip at the cutoff shear is ascertained by an optical detecting device.

Crimp and Puck-Load Turret

The crimp and puck-load turret is a multipurpose unit consisting of a frame weldment and revolving turret of construction similar to that of the cup feed, powered from a horizontal drive shaft and gearbox as are other stations in the pilot line. It is located at the right end of the line.

The turret mounts four types of station modules in pairs, 180 deg apart. The stations are 45-deg crimp, 90-deg crimp, lacquer application, and puck load. To describe the operation of the turret in sequential order, the first stage is the 45-deg crimp operation.

The common endless-chain-and-carrier assembly is supported and located in the identical plane and manner as the preceding turrets. The assembly carries a cup loaded with the three explosive materials and an aluminum disc into the first 45-deg-crimp module on the appropriate revolution of the chain. This station module again consists of two in-line, vertical rams with special punches facing each other on the same centerline as that of the carrier holding the fill cup. The rams are actuated by upper and lower cam plates.

A flat-ended punch on the lower ram enters the carrier from the bottom, raises it into the locating nest on the module, pushes the top of the cup out of the carrier a short distance, and then acts as a support anvil for the cup during the crimping operation.

The upper ram is equipped with a special punch with a 90-deg-included angle conical recess in the lower end. This punch is guided by a hardened bushing to push down over the exposed cup and form the mouth into a 45-deg angled crimp. The punches retract and the cup is then transported a complete cycle around the system to re-enter the crimp station in line with the adjacent 90-deg crimp station module.

The 90-deg crimp station module is similar in construction to the 45-deg crimp station module, but both upper and lower punches are flat ended and VIT sensor flags are mounted on the rams. Again, the lower punch acts as a locator for the carrier and anvil for the crimping operation. The upper punch descends, pushing the cup down into the carrier and against the lower punch, forming the 90-deg crimp to the top of the cup. At this moment, both punches are fully extended, and the flags mounted on the rams pass under the VITs. A readout of the relative position of each punch and the length of the crimp cup is then provided.

Fixed flags mounted on the turret between the 90-deg crimp modules provided for calibration of the VITs. At the back of the turret, the punches are brought together so the punch tips touch. An additional set of VITs is read, thereby calibrating the module each revolution. The cup is then transported another cycle and re-enters the turret in line with the adjacent station module for lacquer application.

The lacquer-application module is similar to those used for crimping. The lower ram guides the carrier up into the locating nest and supports the cup

while the upper ram descends, just touching a lacquer-applicator nozzle against the top crimped surface of the cup. A mechanical stop provides flow adjustment for the applicator nozzle.

Another mechanical stop prevents the lower punch from contacting the lacquer applicator at the calibrating point on the rear of the turret. The metering applicator nozzle and reservoir can be quickly detached from the upper ram.

Both rams are then retracted, allowing the chain and carriers to cycle and re-enter the turret in line with the puck-feed station module.

To facilitate the puck operations, various items of equipment are mounted around the turret. To the left of the turret, a starwheel singulates the plastic pucks from a V-belt powered transfer plate. The pucks are supplied to the starwheel by a vibratory feeder system similar to the cup-feed system. The empty puck is plowed out of the starwheel and into a nest on the turret module. The puck is retained in the nest by two spring-loaded detent buttons. This station module differs from the preceding modules in that it has only a lower ram. This ram is raised to push the carrier up into the locating nest; then, after the puck has been inserted into its nest, the ram is raised farther, pushing the crimped and lacquered cup out of the carrier and up into the plastic puck.

As the turret revolves, an air jet gently blows from the puck nest. This air blast is not enough to eject a puck from its detent buttons, but is enough to eject a cup into a funnel and takeaway chute if no puck is present. This nest "cleanout" takes place at a point approximately 45 deg from the puck-insertion point. A container of neutralizing liquid is placed under the turret-mounting plate to receive the ejected cups. At 90 deg from the puck-insertion point, the lower ram starts down, and an acceptable cup and puck assembly is ejected by means of a computer-controlled, solenoid-operated air cylinder and a spring-loaded, horizontal ram at the back of the nest.

The puck slides onto a chute inclined at 45 deg and goes through a slowly moving counter-rotating V-belt unscrambler and into a chute that slides the puck onto a takeaway belt to the drying oven. If the cup is rejected upstream by the inspection system for any reason, the air cylinder ejector is not actuated, and the component remains in the nest and travels to a point approximately 180 deg from the puck-insertion point. A fixed cam then mechanically actuates the horizontal ram every time to ensure nest clearance. This is the reject station. Failure of the accept system will cause good cups to be rejected, so the system is fail-safe. A chute-and-takeaway duct funnels all rejected parts down into a container under the table containing a neutralizing solution. This completes the production cycle, leaving the chain carrier empty for repeat operations.

Brushing and Aspirating Station

The purpose of the brushing and aspirating operation is to loosen and aspirate any powder or particle stuck to the carrier surfaces or in and around the cup. This is achieved by means of a tubular brush, a central air nozzle, and a peripheral vacuum line. These components are housed in a cylinder attached to

the upper ram. When the ram moves down, the housing interfaces with a chamfer on the cup carrier through a tapered bore and provides accurate location as well as nearly airtight enclosure; this prevents scattering of loose particles and makes the aspirating more effective.

During the last phase of the upper ram downstroke, the circular brush sweeps the upper faces and sides of the carrier, loosening all particles adhering to these surfaces. At the end of the stroke, the central nozzle sends a short airblast into the cup, and any loose powder remaining in the cup flies out and is immediately aspirated by the vacuum line. The vacuum is then pulsated, generating a powerful air influx from the small lateral holes in the housing, through the brush, and into the vacuum line. The pulsating mode (alternate air blasts and suction in fast sequence) dislodges all particles on the carrier faces and between the brush bristles.

Throughout the cleaning cycle, the function of the lower ram is to align the carrier with the upper housing by means of the tapered center pin (the same as in previous operations) and maintain the carrier in its raised position. Because this is done through a rubber spring attached to the lower ram, positive contact between carrier and brush housing is easily achieved with a minimum of adjustment.

The air and vacuum valving system is the same as that used in the loading turret.

Lacquer Drier

Detonators, in individual pucks, are ejected from the unload turret with freshly applied, wet lacquer on their upper surfaces. They are then conveyed through a drying oven in preparation for packaging. The drier assembly consists of the following major components:

- Feed conveyor
- Drier conveyor
- Transfer wheel
- Drier oven

Feed Conveyor. The pucks form a solid line on a chute as they are discharged from the unload turret onto the feed conveyor. The surface of the conveyor is a narrow belt moving at 90 deg with respect to the direction of motion of pucks sliding down the discharge chute. The conveyor moves fast enough to space the oncoming pucks 1 inch apart.

Drier Conveyor. The drier belt conveyor is 2-ft wide. Its direction of motion is 90 deg from and below that of the feed belt. The feed belt extends beyond the surface of the drier belt on both sides. Where the belts overlap, a sloping plate is provided for pucks to slide down from the feed belt to the drier belt.

Transfer Wheel. A transfer wheel directly above the feeder belt pushes the pucks off the belt onto the slide in groups of 20. Paddles on the wheel rotate continuously in synchronization with the feed belt so that a paddle sweeps across the belt each time a group of 20 pucks has moved into position opposite the side. A thin guide bar, located low enough to avoid interfering with the transfer wheel paddles, aligns each group of 20 pucks parallel to the paddles in preparation of pushoff. Alignment of the pucks is maintained as they slide down the chute together and come to rest on the drier belt.

The drier then carries the detonators into, through, and out of the oven. The velocity is such that each group of 20 pucks sliding onto the belt forms a row 1 inch behind the preceding row of pucks.

A single drive unit powers the feed conveyor, the drier conveyor, and the transfer wheel. The unit is connected to the drier conveyor at the point where the conveyor leaves the oven. The drier conveyor transmits power through a pulley at its other end to the feed conveyor and transfer wheel; therefore, both conveyors and the transfer wheel remain synchronized at all times.

The drier assembly design provides the following features:

- An oven 100 inches long
- A drier belt speed of 5 linear inches per minute
- Rows of 20 pucks every inch along the conveyor

This design results in a production rate of 100 detonators per minute, each detonator dried the required length of time (20 min).

Drier Oven. Drying is done by recirculating hot air inside the oven. Part of the hot air is exhausted at a fixed rate and replaced with fresh air to maintain the solvent vapor content inside the oven air at a constant level.

The air is heated by steam and circulated by an explosion-proof electric fan system. Air temperature and flow are monitored continuously. A thermometer probe extending over the full length of the oven provides an average reading. Flow readings are obtained by measuring pressure differentials at various places in the oven. Either improper air temperature or inadequate air flow triggers an automatic system shutoff switch and an alarm signal.

Sample Station

Sample detonators may be removed on demand from the line following removal from the chain at the unload station. A simple gate moving laterally across the linear flow of detonators to the packaging operation will divert one or more detonators as required, still in the plastic carrier rings for safe handling.

An alternate system would utilize the reject cam on the unload turret to remove a sample detonator, but would divert the sample from the reject chute to the sample chute by means of a gate.

Chain Cleaning and Aspirating

After leaving the unload turret and clearing the packaging area, the transport chain passes through a cleaning tunnel. Rotary brushes, on vertical and horizontal shafts, remove all powder dust and other particles the chain may have gathered in the various work stations. Vacuum heads around the brushes remove the dust as soon as released.

Electrical Control System

The controls and the inspections previously described have been designed to meet all system safety requirements.

Control System Definition. The purpose of the nonelectric detonator assembly control system is to perform the following functions:

- Provide operator-machine interface for machine operation
- Control the main drive motor in a variable-speed mode
- Operate high-speed reject solenoids and actuators
- Provide a control device for the automatic startup, run, and shutdown of the total system. Individual machines of the system and individual stations of the machines need no separate control, as they are all joined by a common chain and drive train
- Provide a minicomputer controller to interpret measured product-inspection parameters, command accept/reject/sample functions of the assembly line, perform data analysis, and display system performance data at the machine operator station. The controller can be adapted to communicate with a process quality-control system (PQCS) if required at a future time
- Provide a machine simulator to generate signals which might be received by the controller (such a simulator would allow an operator to check out the proper functioning of all control system circuits and logic)
- Provide a detonation detector

Control Design Philosophy. The system is designed to enable operation of the assembly line with the process controller nonfunctional or unplugged. Operation in this case means merely turning of the machine with or without components; however, no quality data are acquired, nor are any parts tracked. This feature is advantageous during the debugging period at the contractor's facility.

Equipment is provided to simulate complex functions and calibrate inspection devices without operating the assembly line.

The logic system is designed for immunity to electrical noise by using CMOS devices (these devices offer significantly greater noise immunity, approx 3.5 volts versus the more commonly used TTL family with approx 0.4 volt) and by using a single-point ground system.

To simplify troubleshooting, the control system is modular. This arrangement facilitates tracking defects to a particular section of the logic, which can then be replaced as a unit. Repair time can thereby be held to a minimum. When designing the control system, safety, reliability, maintainability, and cost were primary design considerations.

Process Control. The process controller performs the following functions:

- Makes real-time analyses of the sensor signals, compares the signals to programed limits, and determines acceptability of individual components

- Tracks components through the machine and provides signals to appropriate "accept" solenoids

- Presents to the displays an updated record of data each 0.5 second, including parts in, parts out, parts rejected, stations disabled on the line, number of parts rejected by each inspection, and other required functions

- Provides records of quality (i.e., number of parts accepted, and number of parts rejected for specific causes) both cumulative and within a preset reporting period

- Inhibits all subsequent filling operations to affected detonators and ejects them into a reject container, when a station has not performed satisfactorily

- Automatically stops the system, when a station does not perform satisfactorily a preset number of times; the preset, located at the console, may be set at any value from one to six

- Inhibits powder transfer if a cup is missing or inverted

Equipment Details. The controller includes a 16-bit-word minicomputer to perform the required functions with the following peripheral equipment:

- Cathode ray tube (CRT) interactive display terminal permitting alpha-numeric display

- Insolated input/out device interfaces

Machine-to-Control-System Synchronization. A shaft encoder is provided on the loading turret. This encoder, mounted directly to the main shaft, provides information for synchronizing the machine tool stations with the controller and provides timing reference for actuation of the reject mechanism.

To provide for precise actuation, good resolution of the encoder is required; therefore, an encoder providing 120 pulses per revolution was selected. With 24 tool stations and a 22.9-inch-diameter turret, resolution of 0.6 inch per pulse is provided.

The encoder also provides an index pulse for verification of location once per revolution to ensure that operations on the turret are based on accurate machine position and are independent of speed or time.

Control Console. The control console provides the interface between the electrical system and the operators. The console contains displays and controls for the functioning of the controller and assembly line through which the operator communicates.

The console displays the status of the various elements within the system and operating efficiency data. Selective commands can be given to the machine for starting, stopping, controlling speed, and inhibiting product entry.

The desk-type control console is equipped with a two-section front panel containing all operator functions and displays. One section containing the indicators is vertical, but the controls will be mounted in a section sloping at a 30-deg angle. Overall height does not exceed 48 inches; this arrangement permits observation of machine functions through mirrors or explosion-proof windows. Components requiring service are accessible from the front of the unit, so the console can be placed against a wall.

Main Machine Drive. The main drive is a DC shunt-wound motor with an SCR drive package. Because the system may be operated at reduced speed during startup, the motor is oversized to allow this type of operation without overheating. The drive is equipped with tachometer feedback and 1% speed regulation. The drive motor meets National Electric Code Class II, Groupe E, requirements.

Speed adjustments are made from a dial on the control console below the speed indicator. Sound human engineering principles were applied to the design of the console to reduce operator fatigue and thereby ensure efficient and safe operation.

Main Machine Drive Controls.

- Jog Mode -- Manual initiation of the jog mode control causes the system and/or machine to move incrementally for trouble shooting and/or adjusting machines. This control is also available on each machine. Jogging does not cause acceptance of rejectable items.

- Automatic Mode -- Manual initiation of the automatic mode control causes the system to go into fully automatic run.

- Off -- Manual initiation of the off control shuts down all operations.

Machine Stop Modes.

- Emergency Stop -- Emergency stops can be made when a person is in danger or when the machine may be damaged by continued operation. Either the operator or the chain idler jam detectors can actuate the emergency-stop mode.

Personnel can actuate emergency stop switches from any point along the perimeter of the assembly line by pulling a "clothesline" running along the side of the line at eye level. Emergency stop signals cause a lamp to illuminate, indicating where the jam occurred and to sound an alarm at the control console.

- **Normal Stop** -- The operator at the control console uses the normal stop mode for controlled shutdown of the system.

Inspection. The techniques available for inspection on rotating turrets were (1) use of multiple transducers on a turret (such as LVDTs with a large excursion capability) or (2) single, off-turret, noncontact transducers such as VITs. Based on experience with the primer-insert submodule and on cost considerations, the off-turret method using VITs was chosen. The VITs used offer excellent linearity and reliability. They are used with flags attached to the measuring probes and are actuated by the sensing of the relative height or proximity of the flag to the probe as the flag passes the VIT.

Photodetectors. Solid-state photodetectors are used throughout the system. The source is a light-emitting diode (LED) operating in the infrared spectrum. The LED is driven by a pulse source, and the receiver phototransistor is followed by an electrical filter and associated electronics. The detector responds only to light of a narrow frequency band; it is insensitive to ambient and stray light.

The narrow light beam generated by the LED, operating in conjunction with the small sensitive area of the phototransistor which acts as an aperture, produces excellent resolution of the detector. This design has been proven successful in the primer-insert submodule and the component transport submodule.

Incandescent lights are used for inspections requiring wide-spectrum light sources.

Jam Detectors. Jam detectors are located between turrets near the chain idlers. If a jam occurs in the preceding or following turret, the idler deflects to take up or provide the slack required. When this occurs, the idler intrudes into a jam detector and stops the machine. Serious damage to the equipment can be prevented.

Control Display. A CRT display panel continuously indicates the cycle rate of the equipment and presents information on total numbers of parts processed, rejected, and sampled. Indicators identify a source of malfunction, including detonation and, if desired, the number of parts out of tolerance. Permanent quality data are available from the line printer as desired and is periodically printed from the CRT display.

Detonation Detection. The detonation detection system uses an audio-frequency microphone housed in a dustproof enclosure and a frequency selective amplifier. The voltage at the microphone is in the order of millivolts and is intrinsically safe; a complete explosion proof enclosure is not necessary even in the most hazardous areas.

Experiments will be conducted using the microphone and a storage oscilloscope to determine the predominant frequency generated in a detonation. The design of the amplifier will then be modified to amplify that frequency and reject all others. The output of this amplifier can then be used to operate a relay, sound and alarm, and, if required, stop operation.

Machine Simulator. The simulator enables an operator to simulate all signals which might be received by the controller from other parts of the system under both normal and emergency conditions, and to use those signals to verify proper functioning of the controller. The simulator can perform the following functions:

- Simulate shaft encoder signals (120 pulses per revolution) at rotational speeds of 2 to 50 rpm, panel adjustable.
- Simulate signals from the sensor for the following parameters:
 - Empty chain detection
 - Powder supply level, three stations
 - Fill height, three stations
 - Disc presence
 - Crimp height
 - Sealant presence
- Simulate the following signals from operations monitor sensors:
 - Emergency stop by jam detectors on idlers
 - Emergency stop from switches on the machine
 - Powder level status in powder-supply turret
 - Powder level status in powder-dispensing station
- Simulate the actuation of the various reject mechanisms

Automatic Inspection

The contract scope of work specifies certain inspection operations which must be performed automatically while the pilot line is operating. Additional automatic inspections are provided for the complete prototype line.

Inspection Operations, Pilot System

In high-speed manufacturing machinery, many inspection devices are needed to assure high-efficiency, quality-product processing. Some of the inspections used on the pilot system equipment are required by the contract scope of work; others are included as necessary for the particular concept proposed.

All elements of these inspections which must be located on the machine meet one of the following criteria:

- Explosionproof mechanical design
- Housed in an explosionproof enclosure

- Intrinsically safe

Cup-in-Carrier Verification. Verification that there is a cup in the carrier is accomplished while the cup carrier position is controlled in the rotating turret. Verification occurs prior to each loading of NOL 130, lead azide, or RDX.

Cups are loaded into carriers at the first turret by means of a starwheel. The cups are captured by the carriers and remain in the carriers during the subsequent operations. A miniature LED light source directs a beam of light into the cup/carrier. If the cup is present, the beam is blocked; if the cup is absent, the beam is transmitted through the carrier onto a miniature photodetector system.

The signal processing is shown in figure A-7. The cup/carrier position is determined by a local shaft encoder that correlates timing of the synchronous detector.

After some testing, it was found that device failure also indicates cup presence in the carrier. For this reason, the method of detecting the presence of the cup in the carrier was changed to a fail-safe concept.

The fail-safe concept functions with the use of a coaxially located LED illumination and photodetector. When the carrier is in the proper position, the LED is pulsed and the photodetector is sampled for a cup presence signal. The cup must be present to reflect LED illumination to the coaxially located photodetector. The device fails in a safe mode (i.e., failure indicated the absence of a cup, and subsequent filling with primer powders is not enabled).

Cup-Feed Verification. Verification of the cup feed takes place in the belt following the vibratory feeder. The concept (figure A-8) provides for detection of the presence of each cup as it proceeds past a predetermined point.

An LED photo-optical retroreflective scanner is used. The light beam is projected onto the cup edge and reflected on the optical detector as the cup proceeds under the beam. The electrical signal is transferred from the detector to the processing electronics.

At the processing electronics, the detector signal is used to trigger a retriggerable one-shot. If the cup feed continues at a minimum rate, the one-shot remains set. If the cup feed halts for a given period, the timing circuitry resets the one-shot, and a cup-not-feeding signal is initiated.

Consolidation Height of Powder in Cup and Consolidation Pressure. The consolidation height of the powder in the cup is measured by a VIT. The VIT uses a principle of impedance variation which is caused by eddy currents induced in the conductive target material. The electromagnetic coupling between the coil and the target is dependent on their common separation distance. In the functional system, a bridge circuit is used in a manner that the temperature effects are essentially canceled. In the proposed inspection system, a 0.25-inch VIT is used. Accuracy, linearity, and resolution exceed 0.001 inch. A flag (target) is

fixed to each spring-loaded, cam-operated punch on the consolidation turret so that as the punch reaches its full excursion and is compressing the spring, the flag passes under a VIT. At this instant, a signal is transmitted to the process controller indicating the pressure exerted on the powder through the relationship of spring force versus spring depression. Simultaneously, a second flag attached to the upper consolidating punch passes over a second VIT, and the resulting signal is transmitted to the process controller. The difference between these two transmitted signals is converted to a measurement of the consolidation height of the powder in the cup.

The two measurements are compared with measurement limits stored in the process controller, and if either or both measurements do not meet specifications, the cup is ejected at the reject station.

The inspection for the two parameters, consolidation height and consolidation pressure, for each of the two following fill turrets uses identical inspection equipment, but the acceptance criteria are different because of the accumulation of additional layers of powder.

The VIT inspection system was chosen for the described inspection stations because it is noncontacting, and the mechanical design has yielded an inherently safe package. The noncontacting feature exhibits an essentially infinite lifetime, and the mechanical packaging with the wires encapsulated within a shielded cable creates an intrinsically safe, explosionproof design. The signal conditioner associated with the probe is housed in an explosionproof enclosure.

Foil-Presence Verification. Aluminum foil is used for the disc in the cup. The foil is stored on a roll, and the discs are punched (fig. A-9). The foil-presence verification test determines when the roll is exhausted.

A pilot turret contains stations for each process step. Once each revolution, the foil is advanced an increment, and one disc is punched from the foil. The excess foil is trimmed by a shear. The optical detector is positioned ahead of the shear operation and located off the rotating turret.

The optical detector senses the presence of the punched foil once each revolution. The detector must sense foil from each of the 24 stations. The optical detector and electronics are illustrated in figure A-10. A shaft encoder correlates each station with turret position and provides a timing signal for synchronous detection of the foil.

Powder Cup Level Sensing. Each of the powder reservoir funnels is checked once each revolution to verify that there is sufficient powder in the cup. This check is made by a set of photodetectors and an LED light source. When the powder reaches a level containing five or fewer increments, a light falls on the lowest photodetector and a signal is generated. This signal is used by the process controller to actuate a solenoid. The solenoid operates a mechanism which activates air pressure. The pressure unloads the metered resupply charge to fill the next pocket in the powder carrier which coincides with the powder cup requiring refill. The second photodetector detects an overfill. In this event, an alarm is triggered, and the machine is stopped. Both

these sensing operations are fail-safe because a loss of illumination will stop the filling process.

With the shift in emphasis to the alternate design (less complex) for the metering turret/supply turret, the powder level detection method previously described had to change.

The new powder level detection concept employs a paddle wheel and proximity detector. A paddle mounted in a fixed position is designed to ride on the powder surface as the load turret rotates. When the powder level decreases, the paddle follows the level and raises a flag which is connected to the paddle along a swivel. The raised flag is, in turn, detected by a proximity device which is set to recognize a given threshold. Three identical devices are required to signal that any of three powder levels are low.

Verification of Presence of Disc and Sealant. The devices to verify the presence of the disc and sealants are identical. The only operational difference is that the accept-reject limits are set at different levels because of the difference in reflectivity between an unlacquered aluminum disc and an aluminum disc coated with green sealant lacquer.

These inspection devices are mounted near chain idlers so that each cup is inspected as it passes around the idler. Two small LED sources (one green and one red) are focused on the cup and are simultaneously pulsed as the cup passes the point. A single photodetector is mounted above the inspection position, and the reflective signal from the cup is focused on the photodetector surface (fig. A-11).

The relative response of this system is shown in figure A-12. An electronic comparator system in the process controller determines acceptable parts according to preset limits in the memory.

Crimped Detonator Length. The length of the crimped detonator is measured by the inspection system previously described (VIT).

Puck-Feed Verification. The puck-feed verification will be identical to the cup-feed verification (LED).

Sealant-Drying Chamber Air Flow. The airflow through the drying oven is monitored by an explosionproof MERCROID Type PPQWE-3-X3A differential pressure control. The trip point on the control is adjusted to turn on a lamp on the control console to indicate when the airflow decreases to a critical point at which complete drying cannot be accomplished.

Sealant-Drying Chamber Temperature. The temperature of the drying chamber will be monitored by an explosionproof MERCROID Type DAE-35-435-4129 temperature control with a number 5 bulb. The temperature-sensing bulb, a 10-ft tube, is hung in the oven so that it senses the average temperature of the oven. The two adjustable trip points are set at temperatures slightly lower and slightly higher than the normal operating temperature. They cause illumination of a warning light on the control console whenever the temperature reaches either of the preset trip points.

Presence of Aspirate Solution (Water). The presence of sufficient water to aspirate properly is detected by an explosionproof MERCOID Model 401-4EV liquid-level control. The high and low trip points on this device are adjusted for normal level and wired so that a lamp on the control panel illuminates if the level deviates from the normal.

Presence of Vacuum. An explosionproof MERCOID Type DAE-31-3, range 2, pressure control is used to detect loss of vacuum in the brushing and aspirating stations. The control is adjusted so that if the vacuum decreased to an unacceptable level a light on the control panel illuminates.

Air Pressure. When the air pressure decreases to a point at which fluidizing of the powder is no longer satisfactory, a lamp is illuminated on the control panel. An explosionproof MERCOID Type DAE-31-2 pressure control with the proper pressure range is used for this control. The trip point on this control is adjustable.

Inspection Operations, Prototype

A number of inspections in addition to those proposed for the pilot system are proposed for the prototype.

Detonator Cup Storage. A large-capacity cup-storage hopper is used prior to the cup-feed mechanism. This hopper maintains an adequate level in the cup-feed, vibratory-bowl feeder.

The storage hopper is manually loaded. A low-supply detector in the form of a height gage (fig. A-13) connected to a ball float is used to signal the loader/operator. The height gage is connected to visual and audible alarms at the control console.

Cup Dimensions. An optical gage for checking cup height is illustrated in figure A-14. The gage consists of a projector, collector lens, and linear detector array. Cup height is determined by scanning the linear detector array.

Cup Diameter. Cup diameter is determined by an air gaging system as illustrated in figure A-15. As the cup translates past the air gage, an undulating wave form is created. By using a peak-detector circuit, the presence of a cup is determined and the cup diameter is measured.

Detection of Splits, Cracks, and Cuts. Cups are checked for splits, cracks, and cuts (fig. A-16). A small collimated light beam is passed through a diverging lens near the cup mouth, illuminating the cup interior. Splits, cracks, or cuts in the walls cause light to leak through. The integrating hemisphere collects the leaked light and focuses it on the detector.

Foil Thickness Verification. The actual thickness of the foil is verified by a VIT electronic micrometer system manufactured by Kaman Science Corporation. In this system, two VIT units are placed as shown in figure A-17, and the difference signal is calibrated to continuously read the thickness of the foil. This value is used by the process controller for comparison with acceptable limits. If the roll of foil or any of the 24 stations is out of tolerance, the machine is stopped.

Verification of Crimped Condition of Disc. Verification of the crimped condition of a disc is illustrated in figure A-18. A laser strobe is used to illuminate the cup and "stop motion" as the cup is translated by. Reflected energy is deposited on the vidicon camera face.

A return-to-start-of-scan signal is delivered to the camera just prior to initiation of the laser diode strobe. The continuously scanning vidicon then reads out the vidicon picture. Abnormal surface conditions in the disc and cup crimp are detected by electronic processing. In the case of detection of a crimped disc, the crimp causes a deviation in reflected light, resulting in a change in electrical signal which is detected electronically.

Powder Moisture Content. The moisture content of the powder in the powder-resupply system is monitored by a nuclear-type moisture meter manufactured by the Texas Nuclear Company. If the amount of moisture deviates from the desired amount and preprogrammed limits are exceeded, audio and visu the foil. This value is used by the process controller for comparison with acceptable limits. If the roll of foil or any of the 24 stations is out of tolerance, the machine is stopped.

Random Sampling. To facilitate off-line functional testing of production samples, a random sampling feature is incorporated in the design of the machine controls. This feature includes two thumbwheel switches, a pushbutton switch, a sampling solenoid mechanism on the reject turret, and appropriate programming in the process controller. The start station and the stop station numbers are set up on the thumbwheel switches. When a sample is desired, the pushbutton is actuated. The next time the start station is at the sampling gate, parts are ejected until the stop station is reached. These parts are then ready for off-line functional testing.

Self-Calibration of Inspection Devices. Inspection devices are self-calibrating. This calibration is accomplished by providing calibrating samples on the operational turret where feasible. In the case of go/no-go gaging and checks for crimp and cracks, calibration samples are periodically presented to the inspection devices.

Defect Categorization. A list of the number of rejected parts and the inspection stations at which they were rejected is stored in the memory of the process controller. These data are available for printout on the hard-copy device.

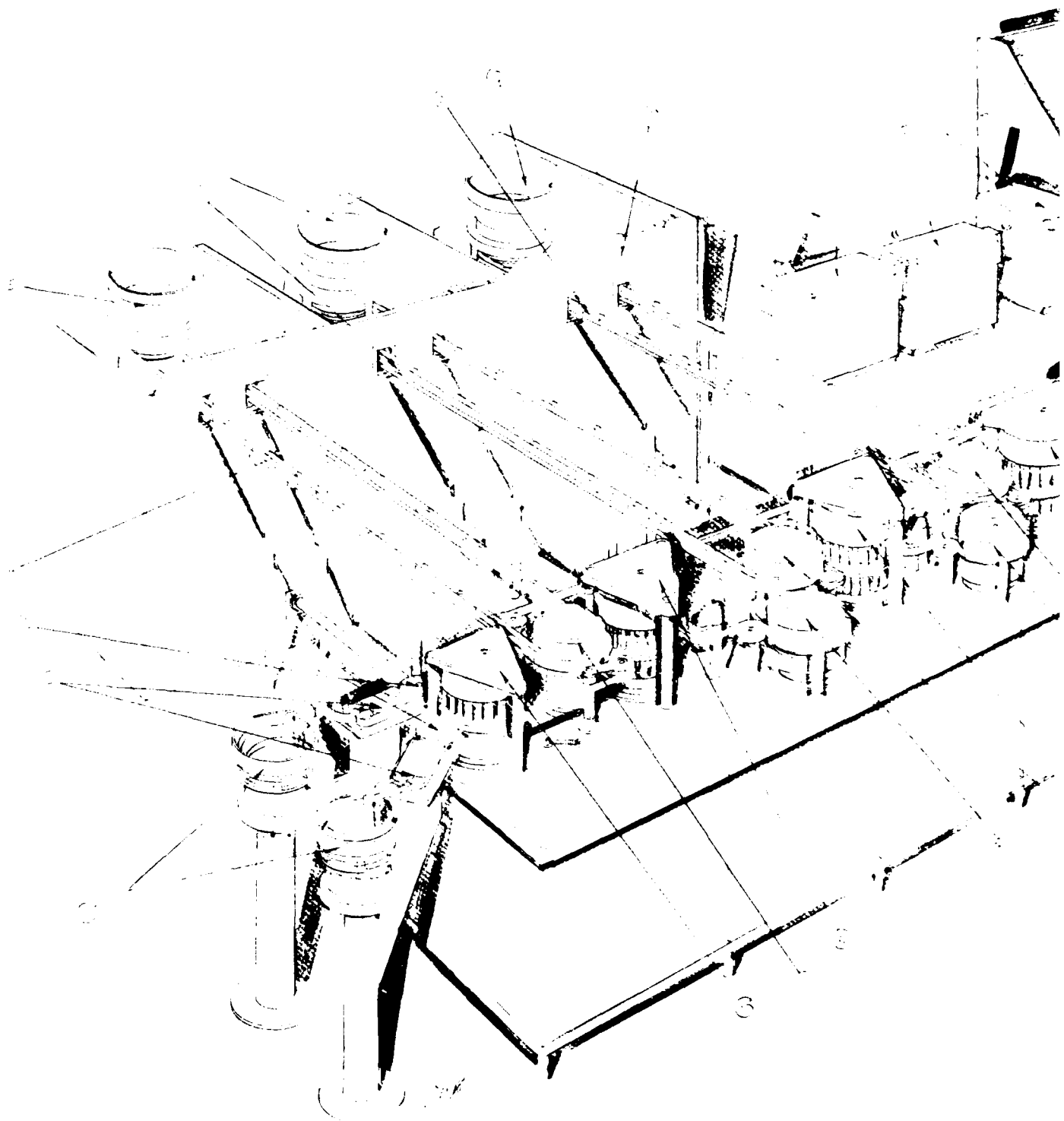
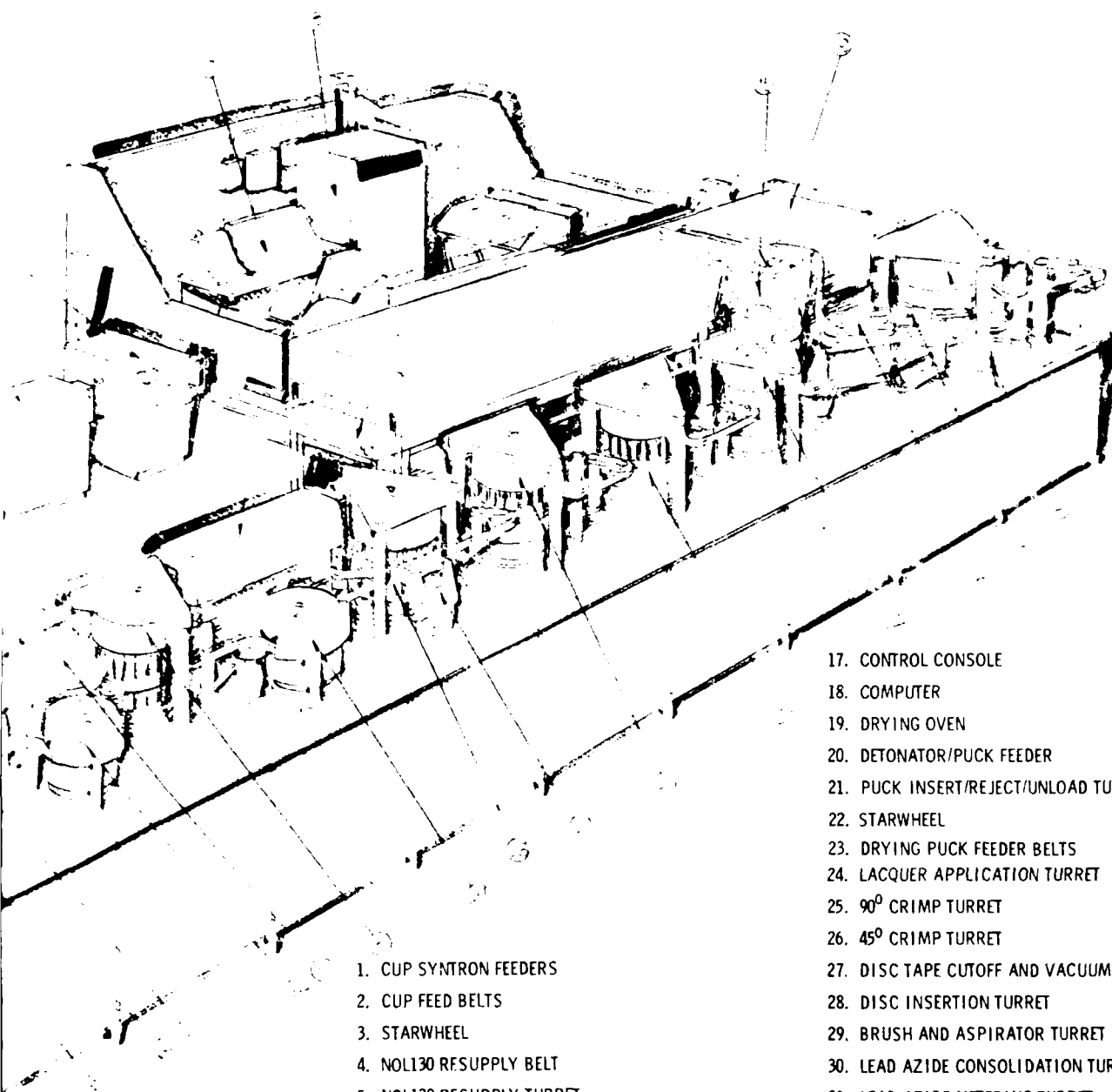


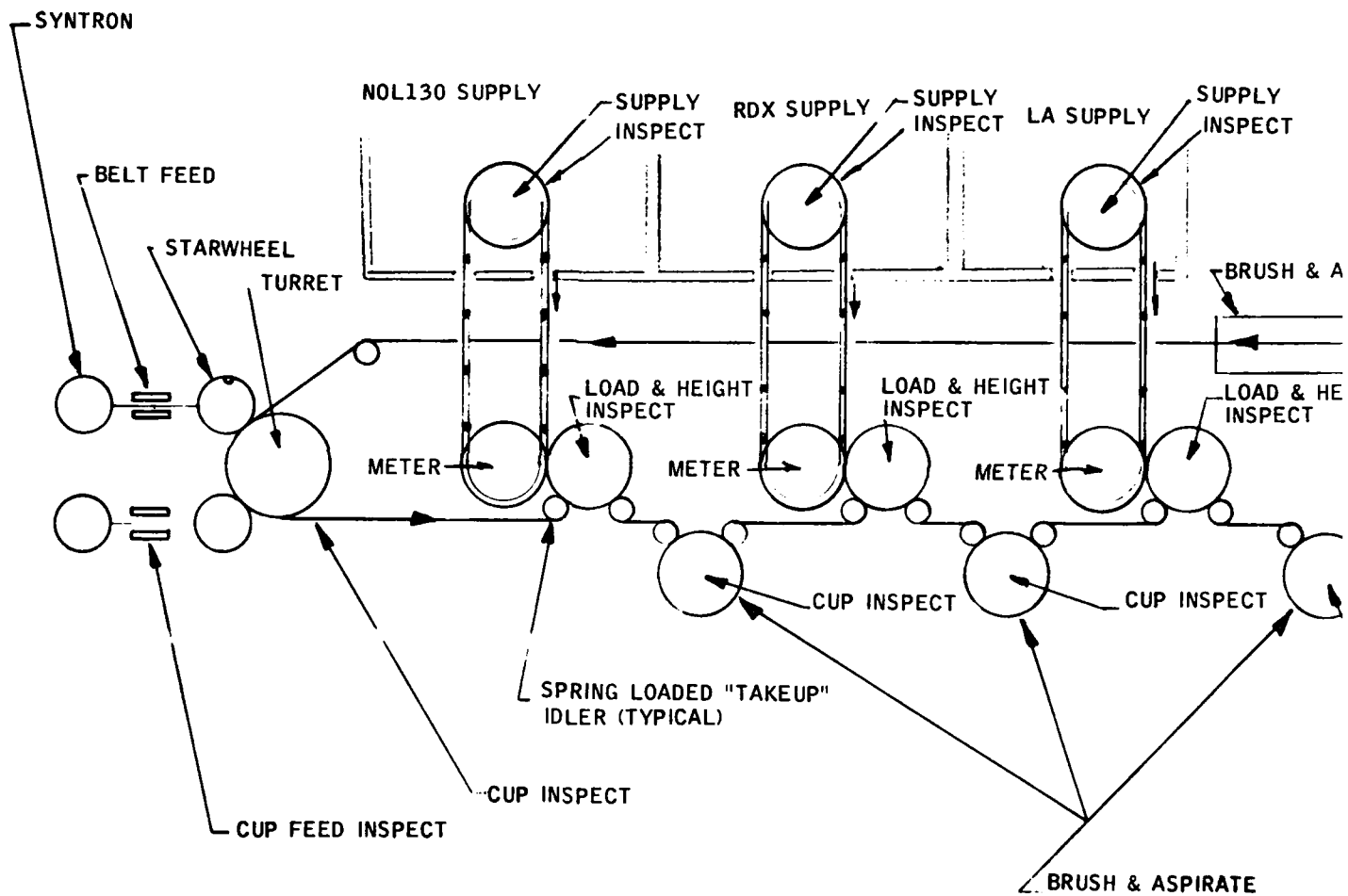
Figure A-1. Production line concept



1. CUP SYNTRON FEEDERS
2. CUP FEED BELTS
3. STARWHEEL
4. NOL130 RESUPPLY BELT
5. NOL130 RESUPPLY TURRET
6. RDX RESUPPLY BELT
7. RDX RESUPPLY TURRET
8. LEAD AZIDE RESUPPLY BELT
9. LEAD AZIDE RESUPPLY TURRET
10. BARRICADE
11. VACUUM PUMP
12. ASPIRATOR
13. AIR DRIER
14. CHAIN BRUSH & ASPIRATOR STATION
15. DRYING PUCK SYNTRON FEEDER
16. DRIED DETONATORS

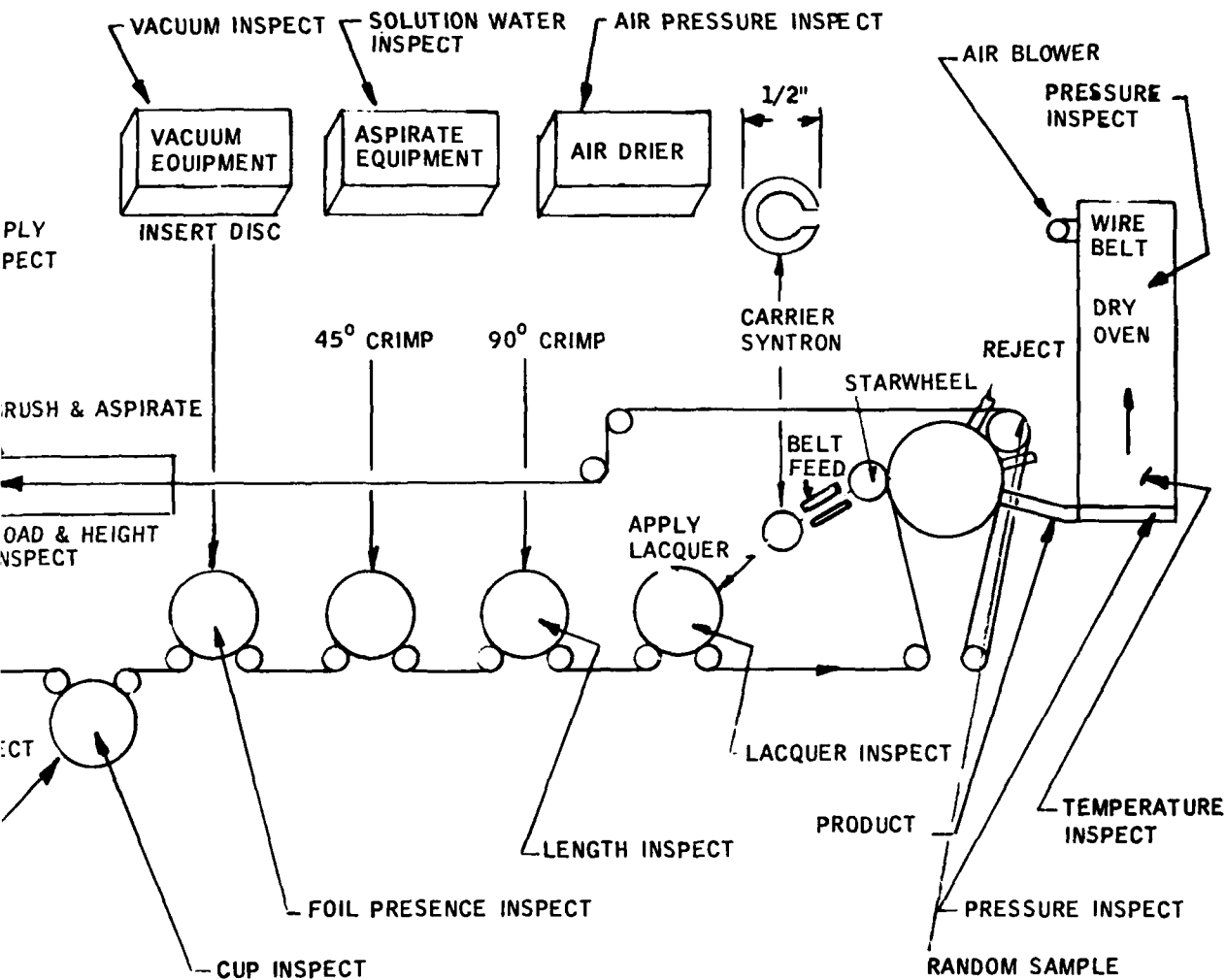
17. CONTROL CONSOLE
18. COMPUTER
19. DRYING OVEN
20. DETONATOR/PUCK FEEDER
21. PUCK INSERT/REJECT/UNLOAD TURRET
22. STARWHEEL
23. DRYING PUCK FEEDER BELTS
24. LACQUER APPLICATION TURRET
25. 90° CRIMP TURRET
26. 45° CRIMP TURRET
27. DISC TAPE CUTOFF AND VACUUM STATION
28. DISC INSERTION TURRET
29. BRUSH AND ASPIRATOR TURRET
30. LEAD AZIDE CONSOLIDATION TURRET
31. LEAD AZIDE METERING TURRET
32. BRUSH AND ASPIRATE TURRET
33. RDX CONSOLIDATION TURRET
34. RDX METERING TURRET
35. BRUSHING AND ASPIRATOR TURRET
36. NOL130 CONSOLIDATION TURRET
37. NOL130 METER TURRET
38. CHAIN LOADING TURRET

NON ELECTRIC DETONATOR



All turrets the same size (2 feet diameter).

Figure A-2. Production line schematic



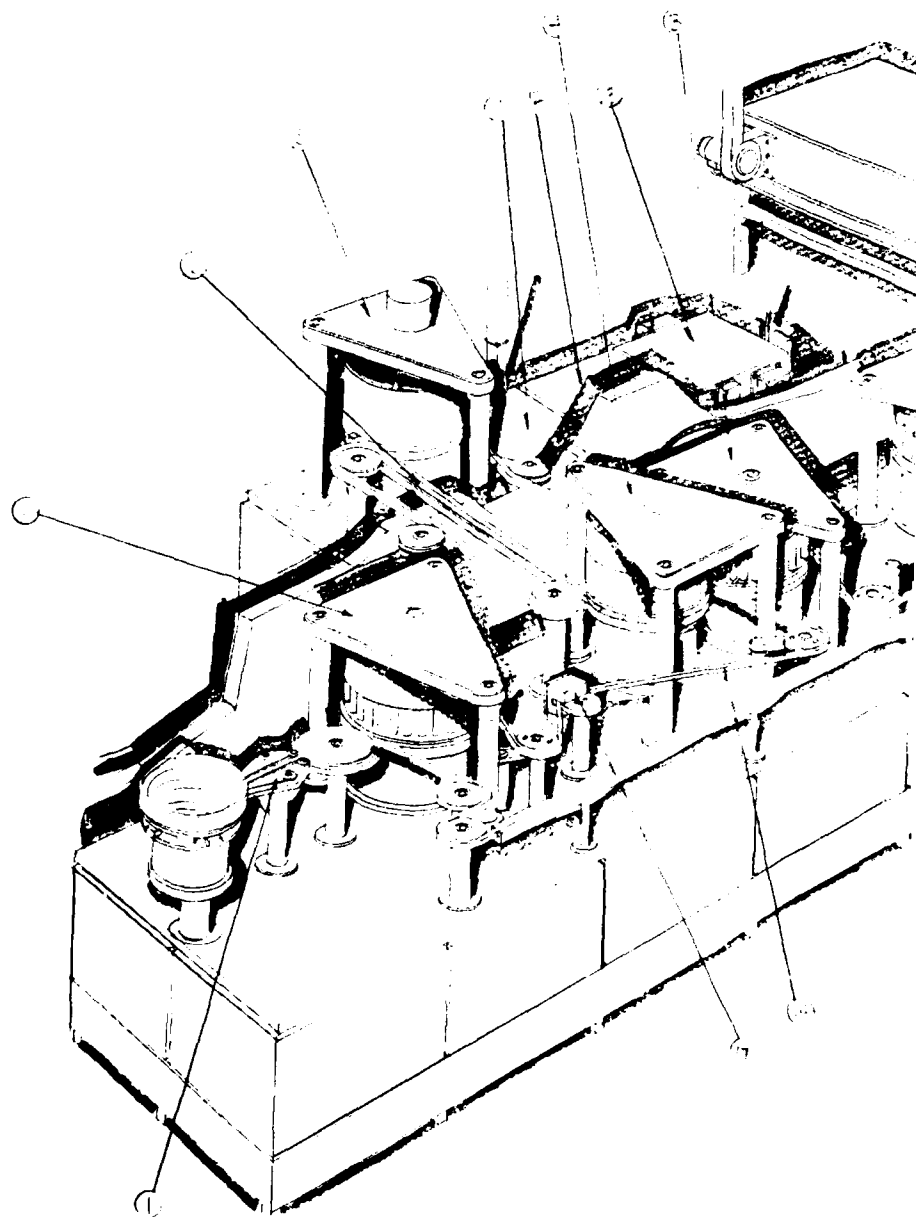
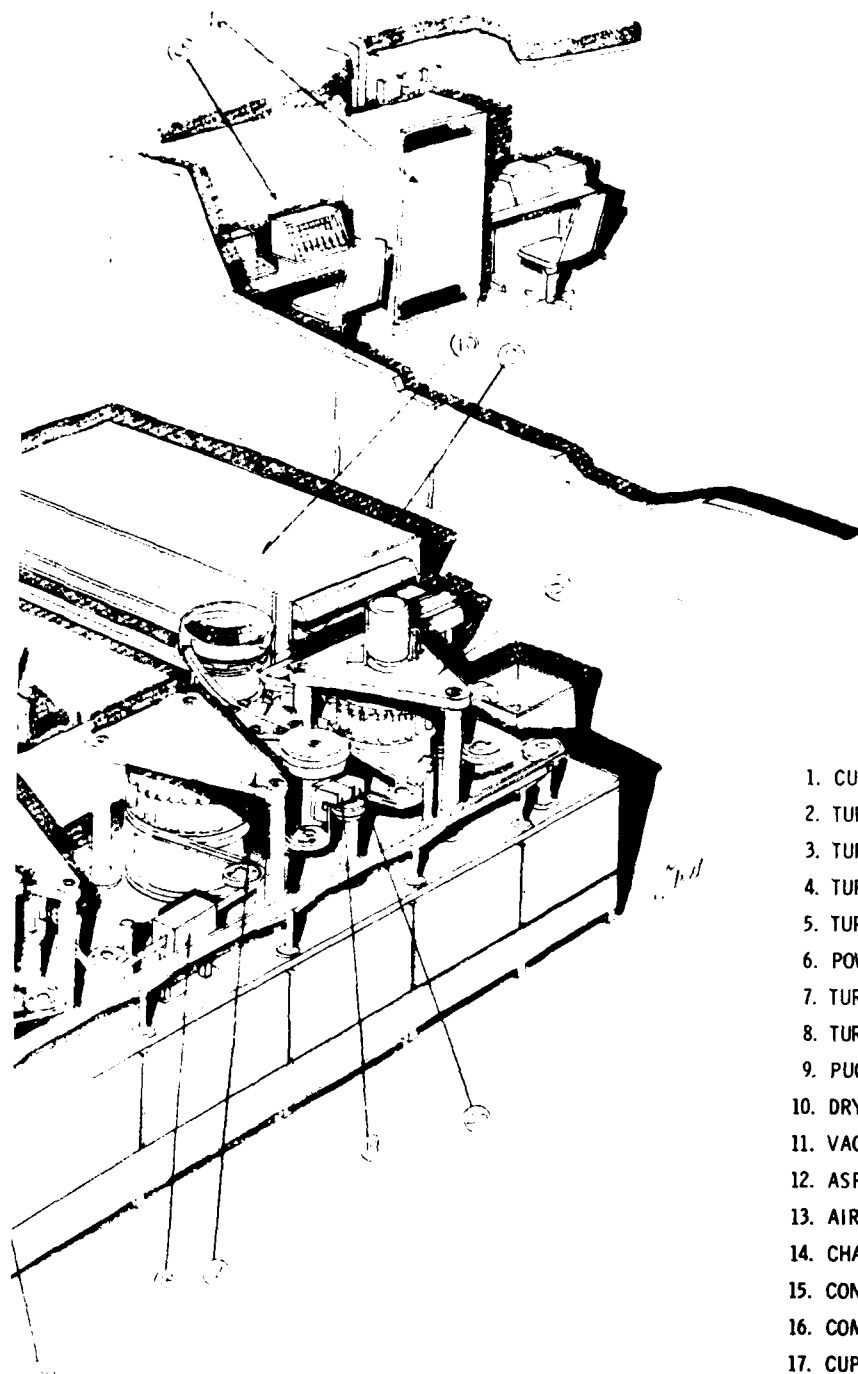


Figure A-3. Pilot line concept



1. CUP FEEDER
2. TURRET NO. 1 - CUP LOADING
3. TURRET NO. 2 - CONSOLIDATE
4. TURRET NO. 3 - POWDER METERING
5. TURRET NO. 4 - POWDER SUPPLY
6. POWDER TRANSFER BELT
7. TURRET NO. 5 - BRUSH, ASPIRATE & SEAL DISC
8. TURRET NO. 6 - CRIMP, APPLY SEALANT & UNLOAD
9. PUCK FEEDER
10. DRYING OVEN
11. VACUUM PUMP
12. ASPIRATOR
13. AIR DRYER
14. CHAIN
15. CONTROL CONSOLE
16. COMPUTER
17. CUP IN CARRIER INSPECT
18. CHAIN BRUSH STATION
19. LACQUER INSPECTION
20. DISC INSPECTION

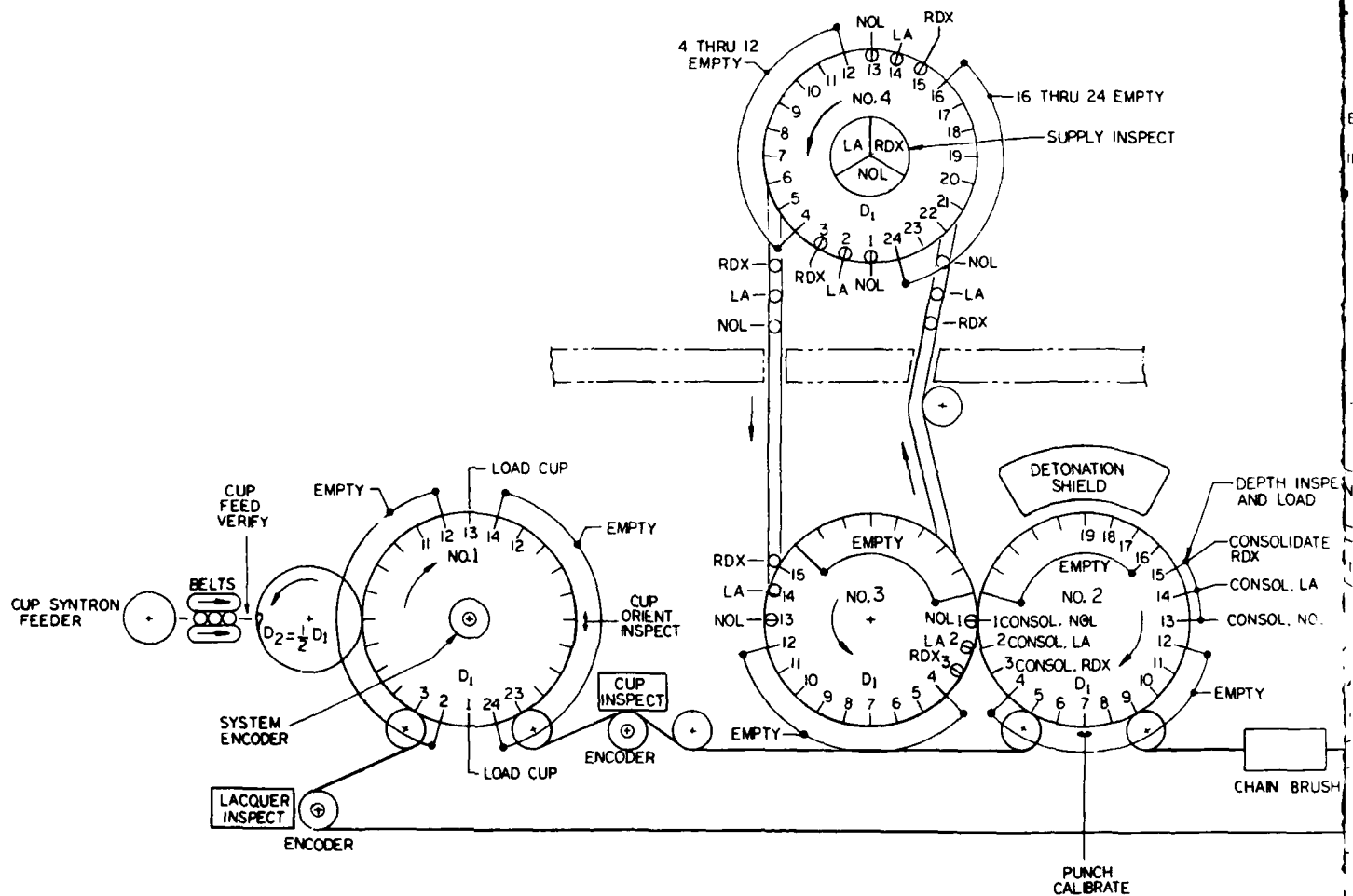
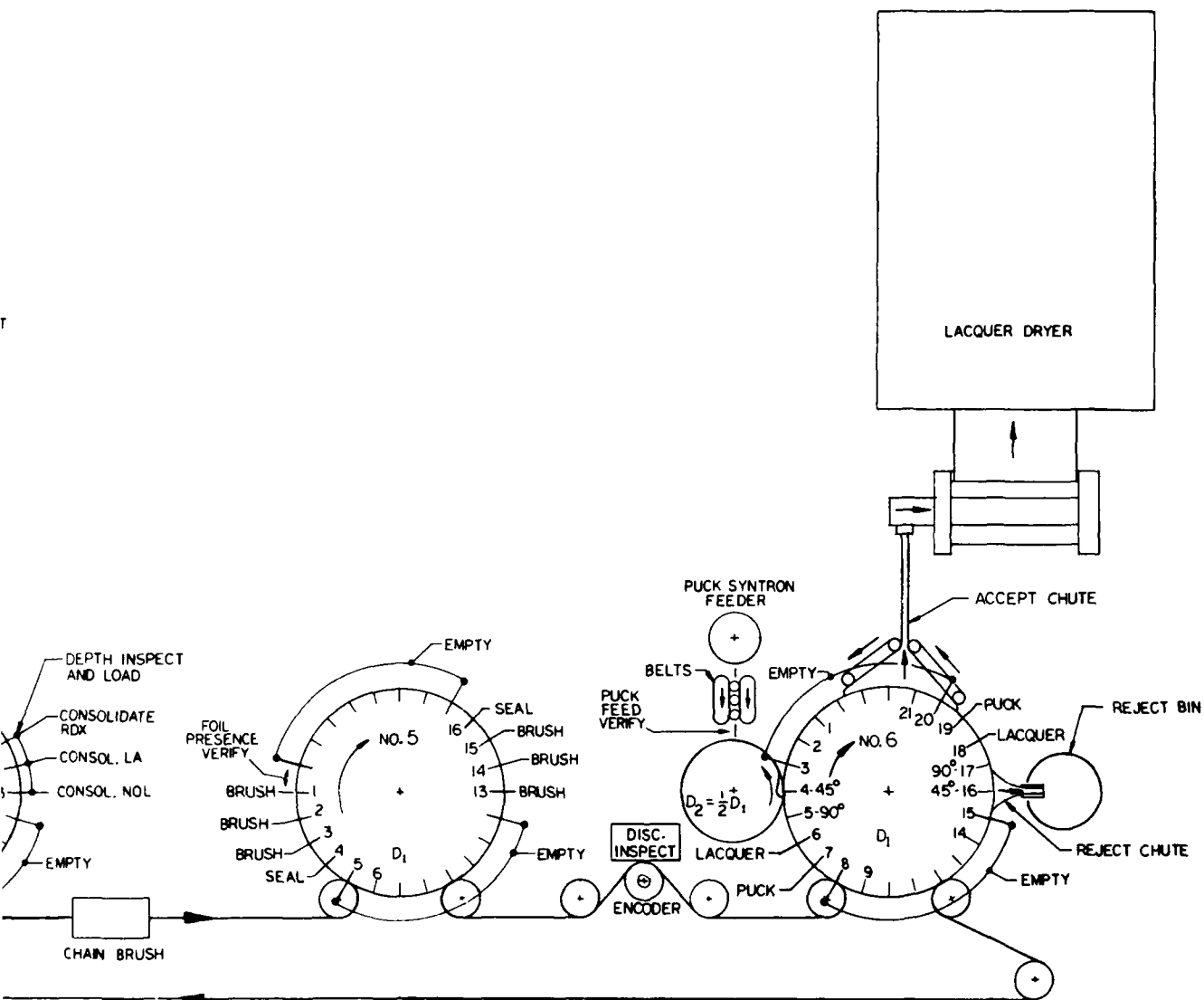


Figure A-4. Pilot line schematic



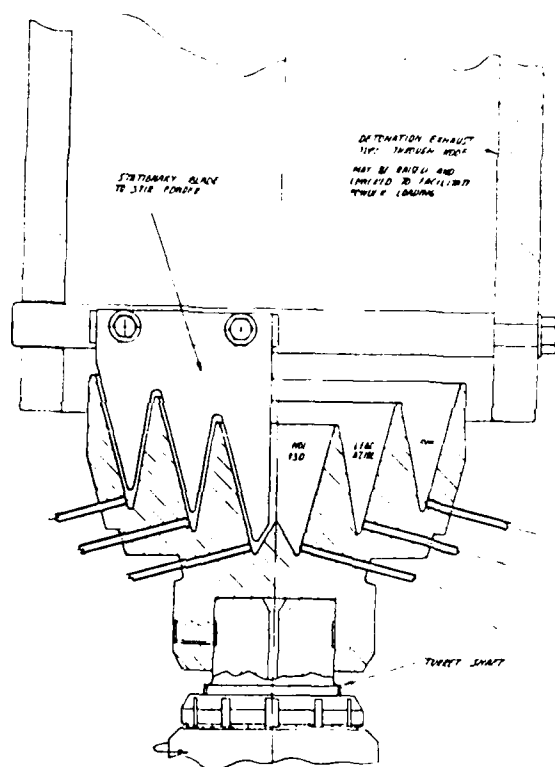


Figure A-5. Pilot line arrangement

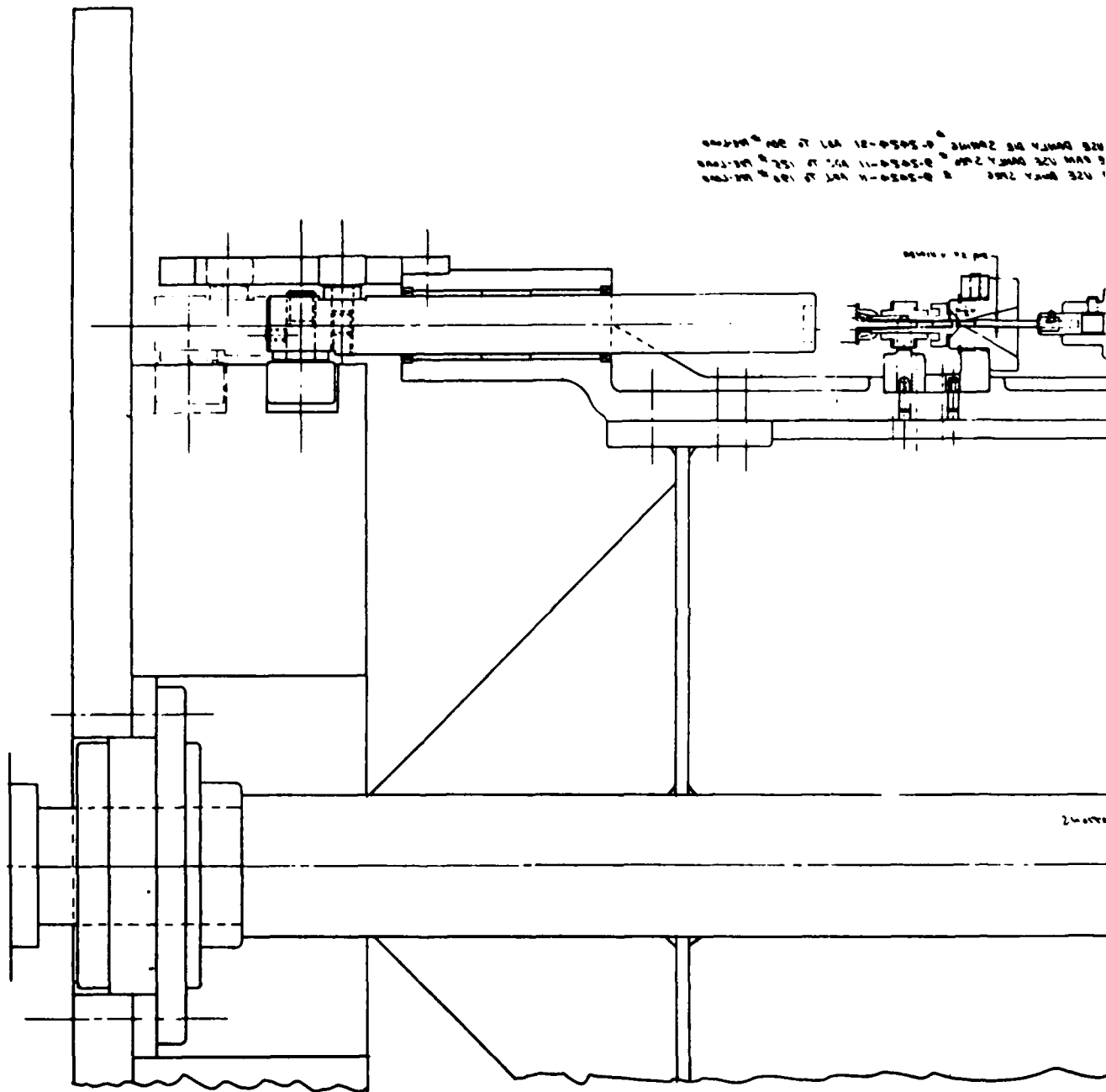
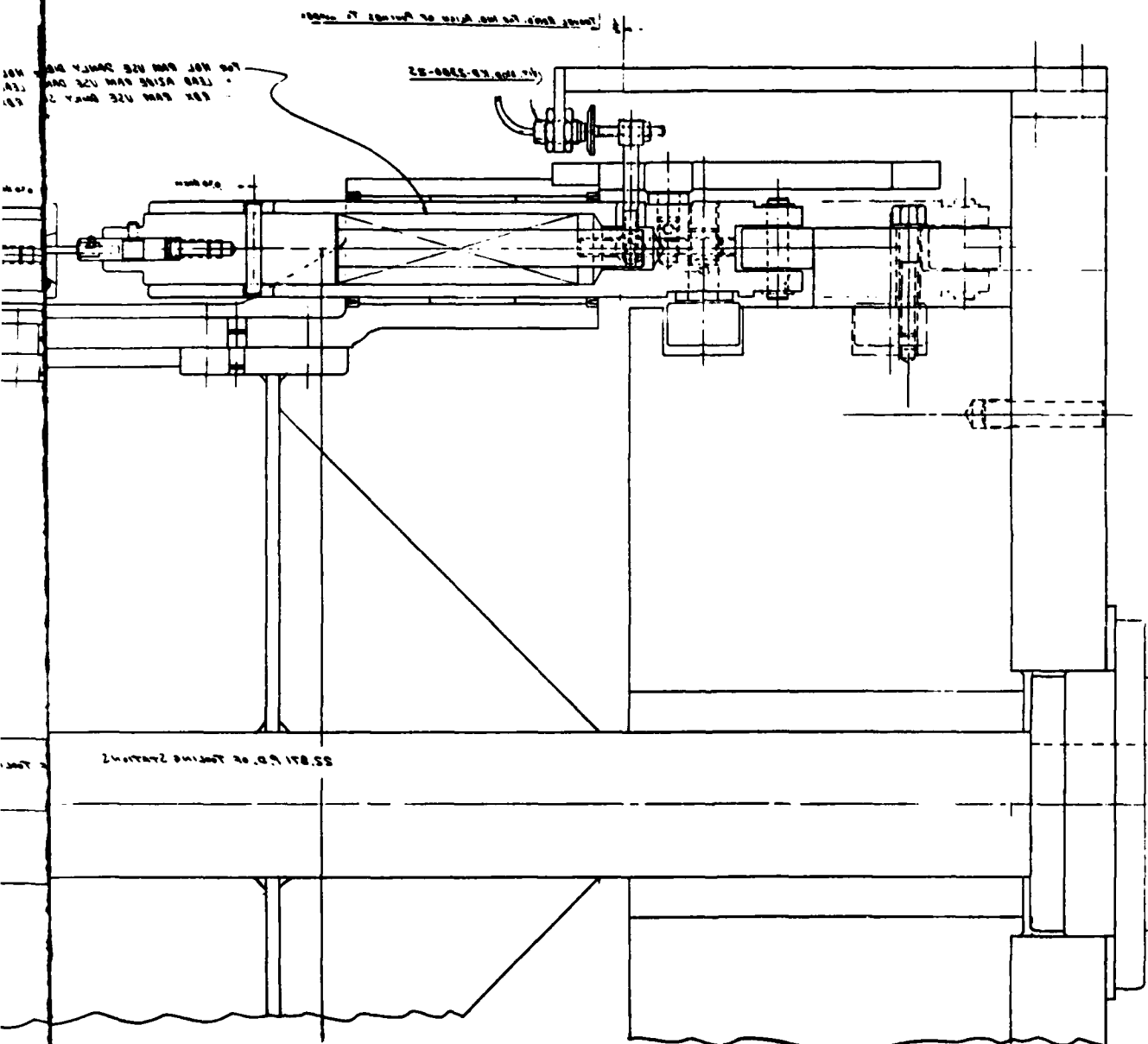


Figure A-6. Consolidation turret assembly



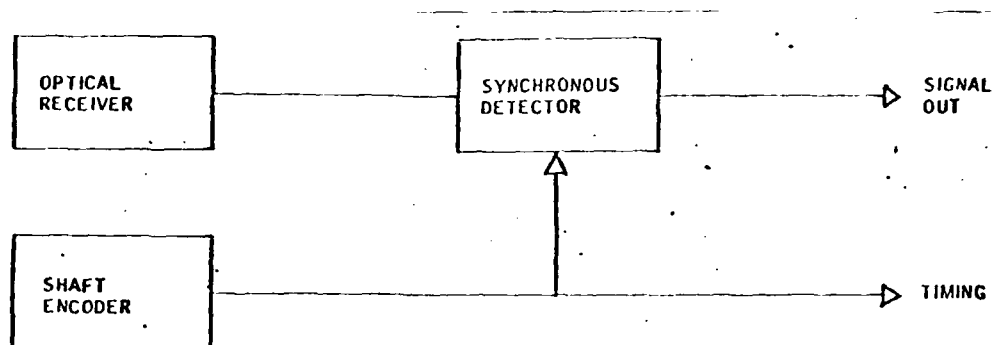


Figure A-7. Signal processing

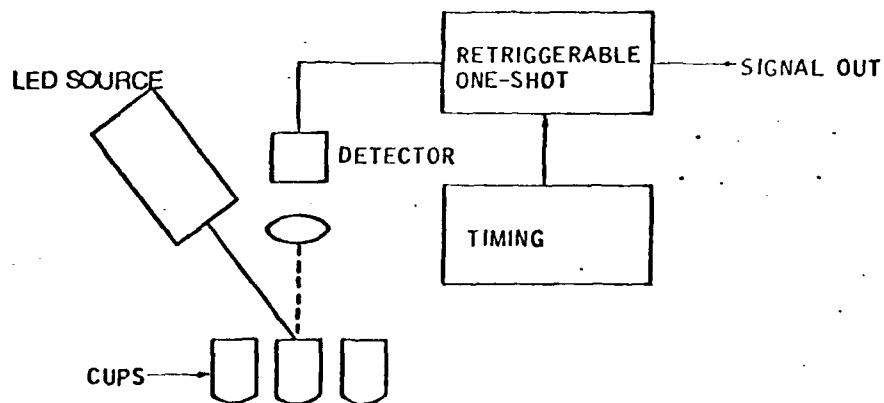


Figure A-8. Functional block diagram, cup feed

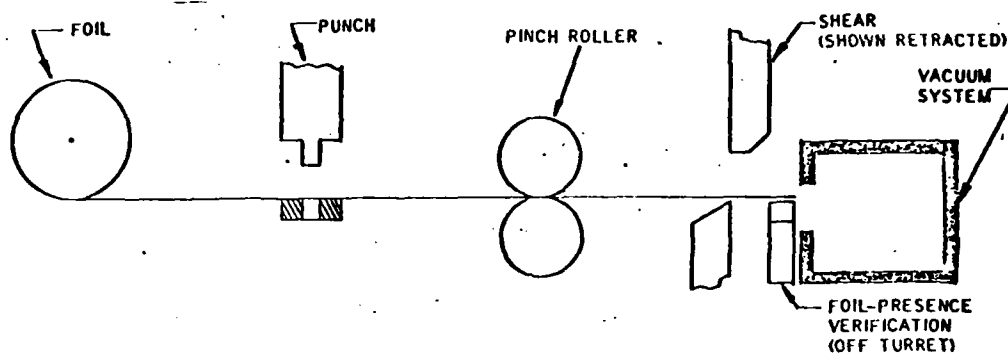


Figure A-9. Foil-presence verification

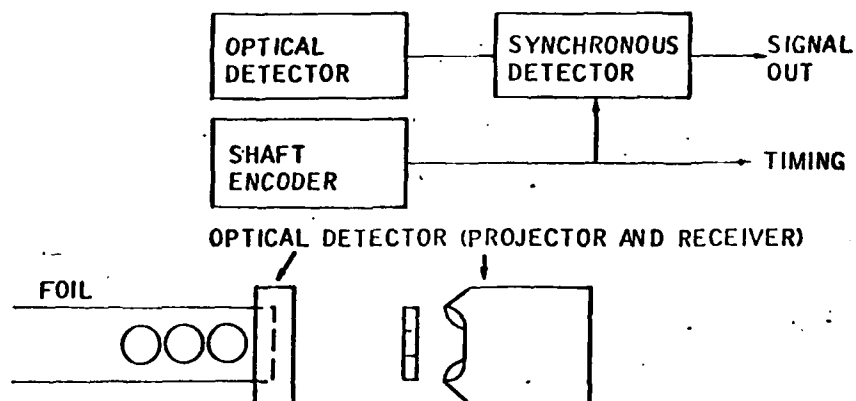


Figure A-10. Functional block diagram, foil-presence detector

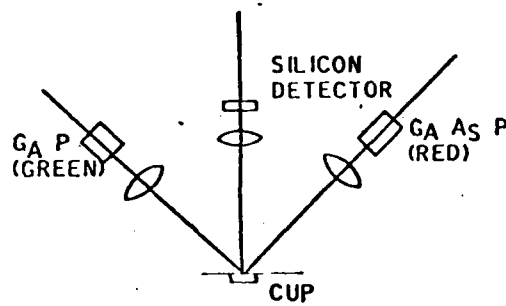


Figure A-11. Verification of disc and sealant presence

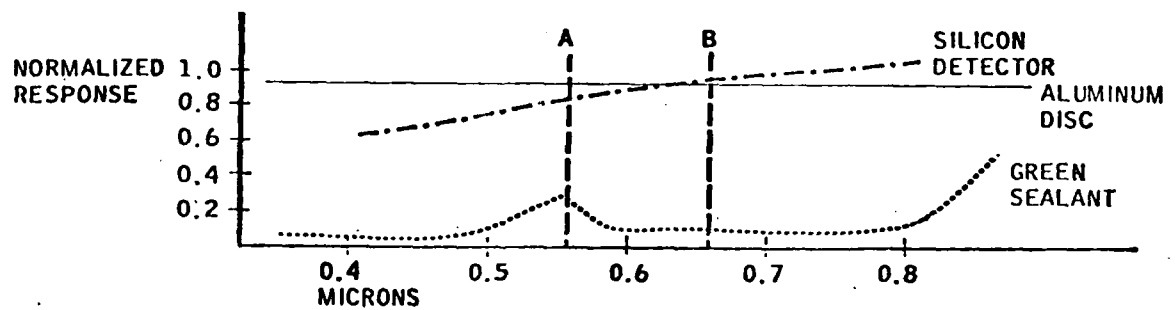


Figure A-12. Relative light response

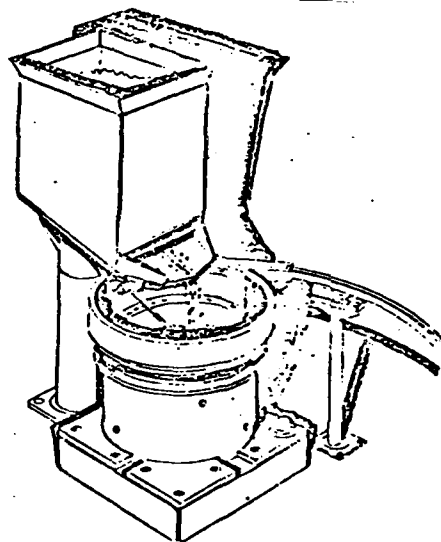


Figure A-13. Low-supply detector

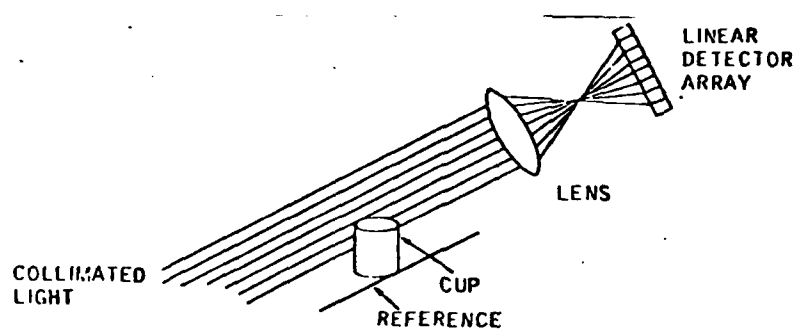


Figure A-14. Optical gage for checking cup height

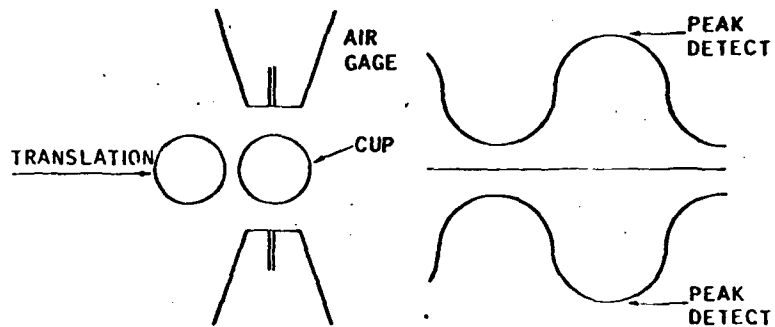


Figure A-15. Air gaging system

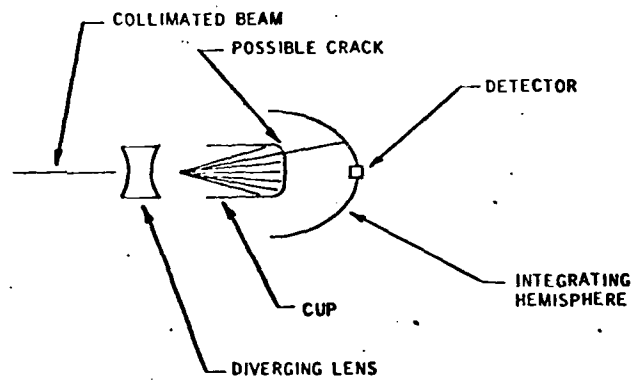


Figure A-16. Process for candling cups

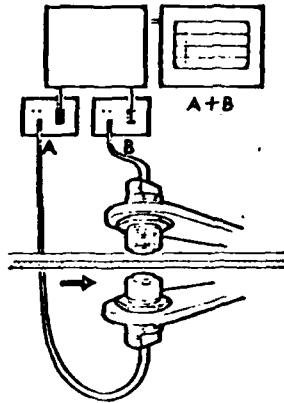


Figure A-17. Differential gaging

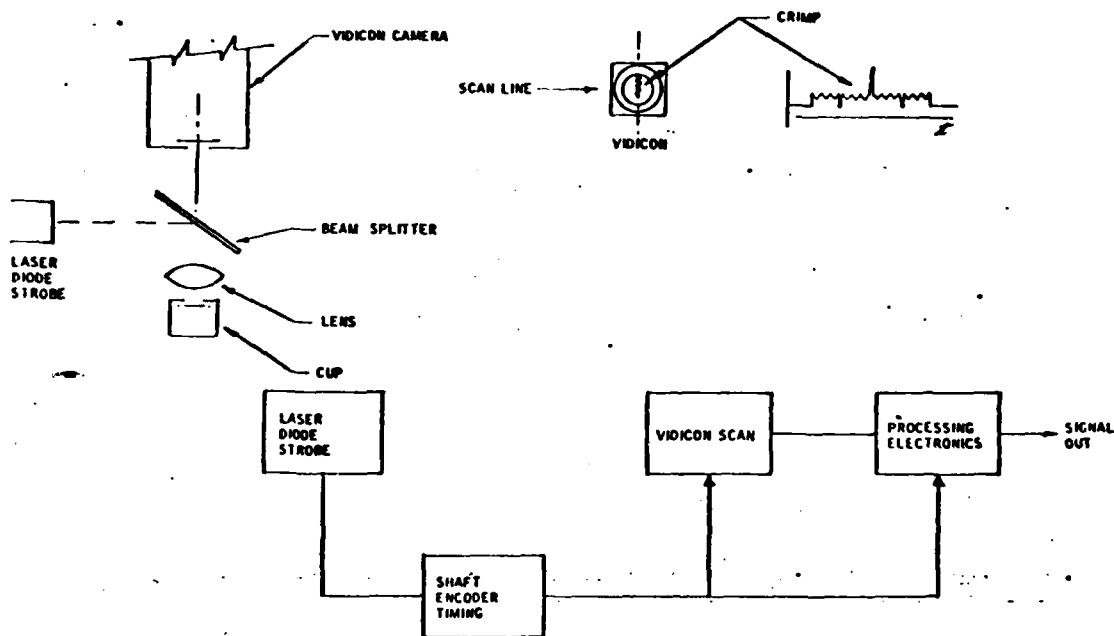


Figure A-18. Crimped disc detection

APPENDIX B

M55 DETONATOR IOWA LOADER CHARACTERIZATION EFFORT

SUMMARY

The ARRADCOM proposed effort to resolve the modernization and expansion requirements for nonelectric detonator production centered about the use of a continuous rotary turret design which would produce detonators at 1200 parts per minute (ppm). In view of this new approach, concern arose as to whether the detonators would have acceptable output characteristics. More specifically, concern arose relative to ram speeds in the three powder consolidation phases and the use of loose RDX for the third increment instead of pelletized RDX. A program to accomplish the preceding, as well as one to establish whether the angular velocity from the new equipment would effect the quality of the detonator, was prepared and executed. Results of the study interacted in the design as it became available. This document presents a compilation and documentation of the efforts and results for future use.

OBJECTIVES

1. Determine the ram consolidation velocity for each of the three increments with the present Iowa loader and compare them to the proposed values for the continuous rotary design.
2. Determine effects on detonator output based on loading with extreme ram consolidation velocities anticipated with the continuous rotary design.
3. Determine effects on detonator output based on anticipated effects on the powder resulting from the centrifugal force imparted by the continuous rotary design.
4. Determine effects on detonator output based on using loose RDX instead of preconsolidated pellets.
5. Note possible correlation between gamma ray densitometer testing, particle velocity testing, and the standard output test.

DISCUSSION

Concern was centered about the high output rate of the continuous rotary equipment subjecting the M55 detonator (fig. B-1) to an environment or conditions exceeding that of the Iowa loader. In keeping with this concern and the stated objectives, a test program was prepared and submitted. To take into account all the variables involved, the program called for the manufacture of some 1700 M55 detonators.

Relative to the present loader, tests and measurements were performed to determine the consolidation ram speeds on the Iowa loader when it is operating at 44 ppm. Ram speeds at the exact moment when the ram touches the unconsolidated powder or pellet are shown in table B-1. A velocity deceleration profile exists during consolidation.

Table B-1. Ram speeds

<u>Explosive</u>	<u>Form</u>	<u>Weight (mg)</u>	<u>Ram Speed (in./s)</u>
NOL-130	Powder	15	2.5
Lead Azide	Powder	51	4.6
RDX	Pellet	19	2.0
RDX	Powder	19	2.9

The difference in the two RDX ram speeds can be accounted for by the different heights (approximately 0.074 in. for the pellet and 0.160 in. for the powder) before the ram made contact.

Following the initial determination of the consolidation ram speeds for the Iowa loader, a load and test matrix was established which consisted of 17 lots of 100 each. This matrix (table B-2) consists of a base lot (1) to be made on the Iowa loader and lot numbers 2 through 17 to be made on the hand line. These lots include three ram speeds for NOL-130, four ram speeds for lead azide and RDX, and extreme angle for each of the powders prior to consolidation, and RDX in pellet and powder form. The principal ram speeds used were 0.5 in./s, which is the punch speed at the low limit of the proposed FMC Corp. design (300 ppm); 2.0 in./s, which is the punch speed at the nominal output (1200 ppm); and 2.5 in./s, which is the punch speed at the high limit of the design (1500 ppm). The powder angle used was 45.58 deg which represents 1500 ppm on the FMC Corp. design. Also, the RDX was loaded in powder form instead of as a pellet in order to determine if the pelleting operation was necessary to make a good detonator.

Prior to the loading of the preceding detonator lots, the Iowa loader had to be made operable and tooled for the loading of the M55 detonators obtained.

While this effort was underway, small lots of detonators were being produced on a hand line in order to establish the process for producing the load and test matrix detonator lots. The detonators produced initially on the hand line failed the output test, and it was determined that the powders were being over consolidated. Upon correction of this problem, acceptable detonators resulted.

Fifty detonators were then loaded with 51 mg (drawing requirement) of lead azide only with the powder at an angle of 45 deg before consolidation on the hand line. These were scanned with gamma rays for density variation, and it was determined that there was no significant density variation in the lead azide from side to side and that such loading would have no effect in output power.

Following the initial angle verification tests, two lots of 50 each, one a standard detonator, and one using RDX powder, were loaded on the hand line using standard ram speeds as a check on the process. These lots were tested for sensitivity and energy output per MIL-D-14978A (dent test) and found satisfactory.

Lot 1 was loaded on the Iowa loader, tested, and evaluated, lots 2 through 17 were loaded on a hand line, tested, and evaluated. The results for lots 1

through 17 and the two extra RDX lots are listed in table B-3. Dent test results for all the variables investigated were acceptable per MIL-D-14978A.

TEST PLAN

Phase I--Iowa Loader Characterization

1. Manufacture 100 each of the following, using suitable instrumentation to obtain consolidation ram and angular accelerations characteristics:

- o Inert loaded M44 detonators
- o Inert loaded M55 detonators
- o Live loaded M55 detonators

2. Test and evaluation techniques listed below.

Phase II--Ram Speed Characterization

1. Manufacture 100 M55 detonators at three different ram speeds for three different powders (total of 900 detonators). Actual speeds shall be defined upon completion of phases I above and Phase I of contractual effort.¹

2. Test and evaluation techniques listed below.

Phase III--Powder Angle Characterization

1. Effort to be performed upon completion of phase II.

2. Manufacture 100 each M55 detonators with the three powders dispensed into the cups at two different angles (total of 600 detonators).²

3. Test and evaluation techniques listed below.

Phase IV--Loose RDX Characterization

1. Effort to be performed upon completion of phase III.

2. Manufacture 100 M55 detonators using ram speed and dwell parameters (to be defined) except using powdered RDX instead of pellets.³

¹ Quantity was increased to 1400 in order to address all variables.
² Quantity was decreased to 150; further testing was deemed unnecessary.
³ Quantity was increased to 200 to provide initial tests.

Test and Evaluation Techniques

1. Inspection of all live loaded detonators for increment heights and densities using a gamma ray densitometer for evaluation parameters and to obtain correlating data for possible inclusion of technique into the automated equipment of Project 4000.

2. Testing of a sample of 39 units from each 100 group in accordance with the current production technique of sensitivity and energy output per MIL-D-14978A.

3. Testing of a sample of 39 units from each 100 group by a more discerning technique of sensitivity and energy output (particle velocity).

CONCLUSIONS

1. Present Iowa loader ram consolidation speeds were obtained. The results indicate that the speeds encountered in the rotary turret concept were less severe than the Iowa loader.

2. Tests on detonators loaded at the extreme ram consolidation speeds, anticipated with the continuous rotary design, resulted in acceptable detonators.

3. Test on detonators loaded under conditions simulating the effect of centrifugal force on the explosive powders resulted in acceptable detonators.

4. Detonators loaded with loose RDX and prepelletized RDX all passed the acceptance test.

5. Results obtained by comparing the standard detonator acceptance test and the particle velocity technique appear to offer general correlation. Correlation with the gamma ray densitometer technique would require more intensive testing.

Table B-2. M55 detonator load and test matrix

<u>Lot^{a,b}</u>	<u>NOL</u>	<u>Lead azide</u>	<u>RDX</u>
1	Standard detonator on Iowa loader		
2	2.0	4.6	2.0
3	2.5	2.0	2.0
4	2.5	4.6	2.0
5	0.5	4.6	2.0
6	2.5	0.5	2.0
7	2.0	4.6	0.5
8	2.5	4.6	2.0
9	2.5	2.5	2.0
10	2.5	4.6	2.5
11	2.0	2.0	2.0
12	0.5	0.5	0.5
13	2.5	2.5	2.5
14	2.5	4.6	2.0
15	2.5	4.6	2.9 ^c
16	2.5	4.6	2.9 ^d
17	2.5	4.6	0.5

^a Quantity of each lot was 100.

^b Lots 1 through 14 and 17 have RDX as a pellet.

^c RDX loose powder and all three at 45.58 deg.

^d RDX loose powder.

Table B-3. Detonator metrics test results

Lot	Description	Fragment velocity (mm/mu)	Dent test		Density (g/cm ³)		Length (mils)		
			Mean	Standard Deviation	NOL	Lead	NOL	Lead	RDX
1	Standard deviation, Iowa loader	3.718	0.01473	0.00160	0.0	3.070	24.3	62.8	54.9
2	NOL, 2 in./s	3.827	0.01527	0.00113	1.924	1.992	23.0	61.6	57.4
3	Lead azide, 2 in./s	3.834	0.01497	0.00113	2.013	2.154	24.5	61.5	56.1
4	Standard deviation, hand line	3.849	0.01427	0.00144	2.641	3.030	23.5	62.1	56.4
5	NOL, 0.5 in./s	3.823	0.01432	0.00128	2.377	2.948	26.1	58.9	55.0
6	Lead azide, 0.5 in./s	3.898	0.01455	0.00103	2.554	2.964	24.1	64.2	53.1
7	NOL, 2 in./s) NOL	3.751	0.01445	0.00123	2.634	3.086	25.7	62.2	54.3
8	RDX, 0.5 in./s) error	3.812	0.01409	0.00147	2.556	2.946	26.3	62.8	52.9
9	Standard deviation, hand line	3.854	0.01412	0.00139	2.541	3.100	25.8	60.5	55.8
10	Lead azide, 2.5 in./s	3.730	0.01388	0.00226	2.723	3.244	25.0	62.2	54.9
11	RDX, 2.5 in./s	3.733	0.01388	0.00198	2.741	3.281	26.7	62.6	53.3
12	All, 2 in./s	3.773	0.01403	0.00221	2.483	3.205	26.8	62.8	52.4
13	All, 0.5 in./s	3.848	0.01488	0.00302	2.786	3.294	26.0	61.9	54.2
14	Standard deviation, hand line	3.816	0.01494	0.00233	2.741	3.280	26.7	63.1	51.9
15	RDX powder, all at 45.58 deg	3.553	0.01324	0.00190	2.860	3.386	29.3	65.6	47.4
16	RDX powder	3.570	0.01715	0.00400	2.795	3.453	27.6	65.8	48.0
17	RDX, 0.5 in./s	3.497	0.01682	0.00458	2.998	3.580	30.2	64.8	46.5
A	RDX pellet (standard deviation)		0.01581	0.00204					
B	RDX Powder		0.01480	0.00219					

NOTES:

Lots 2 through 17 and RDX lots A and B were made on a hand line

2 in./s = nominal ram speed of FMC design = 1200 ppm

2.5 in./s = high limit of FMC design = 1500 ppm

0.5 in./s = low limit of FMC design = 300 ppm

Table B-3. (cont)

Iowa loader (bldg 271) ram speeds are:

NOL-130	2.5 in./s)	
Lead azide	4.6 in./s)	These speeds were
RDX	2.0 in./s (pellet)	used on the hand line
RDX	2.9 in./s (powder)	

45.58 deg corresponds to powder angle at 1500 ppm speed.

Lots 2 and 3 - The detonator holder positioned the detonators off center and resulted in low density values.

Lot 1 NOL density unobtainable.

- A. FILLER, LOWER, PRIMER MIX, NOL 130 -
(100% Approx) (.23 Grains)
- (1) Lead Styphnate, Basic, Type II,
SPEC MIL-L-16355 (40% By Weight \pm 2%)
Alternative is Normal Lead Styphnate
SPEC MIL-L-757
 - (2) Lead Azide, Type 1, SPEC MIL-L-3055
(20% By Weight \pm 2%)
 - (3) Tetracene, SPEC MIL-L-3055
(5% By Weight \pm .5%)
 - (4) Barium Nitrate, Class 1, SPEC MIL-B-162
(20% By Weight \pm 1.5%)
 - (5) Anthony Sulfide, Class 5, SPEC MIL-A-159
(15% By Weight \pm 1.5%)
- CONSOLIDATION PRESSURE 70,000 psi APPROX.
- B. CHARGE, INTERMEDIATE, LEAD AZIDE
(51mg Approx) (.79 Grains)
- (1) ED 1333 Lead Azide SPEC MIL-L-46225
 - (2) Alternative Lead Azide -
Special Purpose MIL-L-14758
- CONSOLIDATION PRESSURE 10,000 psi APPROX.
- C. CHARGE, LOWER, RDX -
(15mg Approx) (.29 Grains)
- (1) RDX, Type 1, SPEC MIL-P-45486
- CONSOLIDATION PRESSURE 15,000 psi APPROX.
- ENCLOSURE

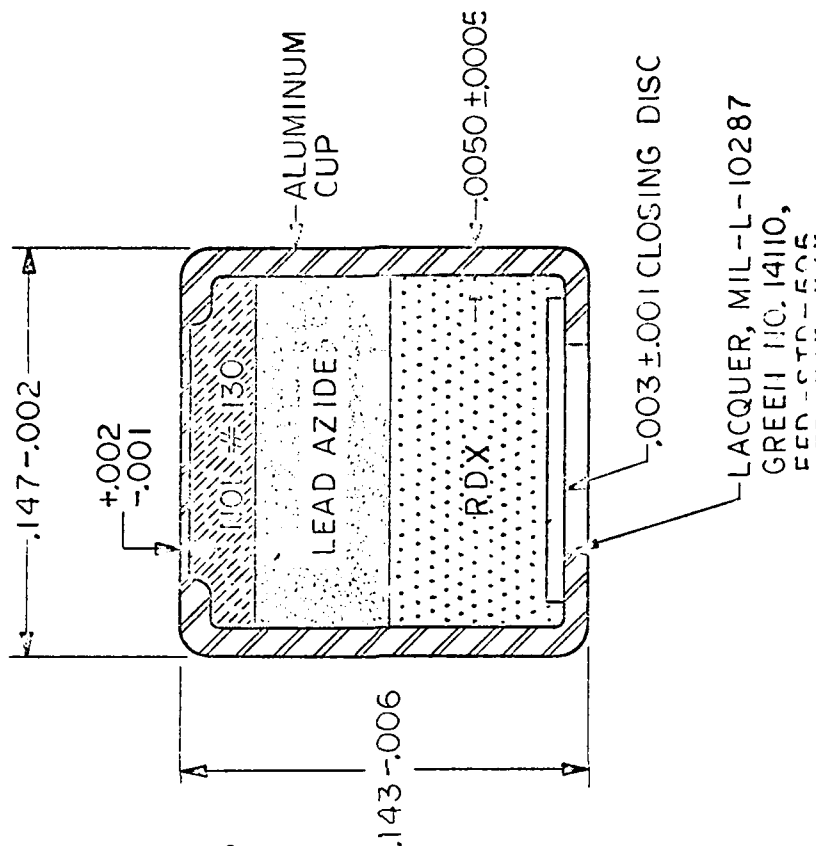


Figure B-1. M55 stab detonator

APPENDIX C
OPERATIONAL SHIELD TEST FOR X4 LOADER

SUMMARY

Existing X4 Iowa loader operational shields in use on the prototype machine are vented through the building roof. Redesign of these shields was necessary to eliminate various problems experienced by these units. Condensation occurring inside the vents due to the cold Iowa winters was a severe problem. Another problem was air draft or a flue effect experienced inside the shield. The 18-inch diameter pipe used to construct the existing shield consumed much needed dial space. A thorough study of the dial layout concluded 16-inch diameter shields with the azide shield offset would allow access to the dial station fixture immediately following the primer consolidating station. A primer consolidation detonation occurring in the dial station fixture could then be serviced at the following station. The vent opening between the inside chamber and the outer compartment on the existing shields prohibits the replenishing of powder while the machine is operating. By eliminating this vent it was felt machine downtime could be reduced by allowing the operator to replenish the powder supply with the machine in operation.

SHIELD DESCRIPTION

The shield (fig. C-1) is constructed of 16-inch diameter, 3/8-inch thick steel pipe. The floor is 1-inch thick steel bolted with 16 one-half inch bolts to the main body. A 1/2-inch thick steel walled compartment approximately 9 inches wide x 7 inches deep x 47 inches long is welded to the front of the pipe. An inner door opening 8 inches wide x 18 inches high provides access between the outer compartment and the pipe area. This is closed by a vertical sliding door of 1/2-inch steel reinforced with four horizontally placed strips of angle iron welded to the curved door. Nylon molybdenum disulfide strips in the door edge and the door guides provide a seal. Access to the outer compartment is by an opening 8 inches wide x 14 inches high. This is closed by a vertical sliding 3/4 inch thick steel door with sealing strips embedded in its edges. Viewing windows (one on each side of the outer compartment) are made of laminated polycarbonate sheet (Lexgard, rated bullet resistant) 1 1/4 inches thick x 5 1/4 inches wide x 16 inches long. Seal strips are embedded in the edges. A flanged section of pipe with a capped end bolts to the top of the pipe body with 16 one-half inch bolts. This shield differs from previous shields in that each compartment is self contained with no venting.

TEST SETUP

The shield was secured to a large base plate and placed in position. The explosive was placed in the operational shield in a cardboard container approximately 6 inches from the shield door. Detonation by means of an electrical blasting cap was controlled from within the bunker. Tests 1 through 4 were conducted 16 April 1980. After test number 4, it was decided not to subject bolts to further stress. All floor bolts and bolts holding the top section should be replaced before continuing. Also the various small holes (for airline fittings and mounting of powder dumper) should be closed by adding machine screws. Test number 5, incorporated with changes. The TNT equivalences established for this test are as follows:

- 1 oz NOL-130 = 0.423 oz TNT
- 1 oz C-4 explosive = 1.078 oz TNT

RESULTS

Test No. 1

27.81 grams of C-4 explosive equaling 125% of 2 oz of NOL-130 detonated inside the outer compartment with both doors closed. No damage occurred.

Test No. 2

55.62 grams of C-4 explosive equaling 125% of 4 oz of NOL-130 detonated inside the pipe area and 27.81 grams of C-4 explosive equaling 125% of 2 oz of NOL-130 simultaneously detonated inside the outer compartment with the inner door open. Some slight damage to the nylon seal strips on the window edges and a small amount of chipping of the window at the knob area occurred. No structural damage was observed.

Test No. 3

111.24 grams of C-4 explosive equaling 125% of 8 oz of NOL-130 detonated inside the pipe area with the inner door closed and the outer door open. The ring of floor bolts were loose indicating some stretching has occurred. One bolt was loose on the ring for the top. The right window knob was stripped off and some further deterioration of window seal strips was evident. Structurally the shield remained sound. All bolts were tightened before the next test.

Test No. 4

139.05 grams of C-4 explosive equaling 125% of 10 oz of NOL-130 detonated inside the pipe area with the inner door closed and the outer door open. This blast loosened the floor bolts and three bolts on the upper ring were loose. The remaining window knob was stripped off and window seal strips were again agitated. All doors functioned properly, and welded joints appeared sound.

Test No. 5

111.24 grams of C-4 explosive equaling 125% of 8 oz of NOL-130 inside the pipe area detonated simultaneously with 27.81 grams of C-4 explosive equaling 125% of 2 oz of NOL-130 inside the outer compartment. The inner door was open and the outer door closed. All bolts were still tight, welded joints were sound, and the outer door operated properly. The inner door was structurally intact but inoperable by hand. Windows remained as before the test, but pressure had forced them up slightly because a holding screw wasn't tightened properly.

CONCLUSION

Since 6.5 oz of powder will be the maximum amount expected to be inside this shield during operation, this shield was considered acceptable for production use on the X4 Iowa loader. Six and one-half oz of lead azide will provide a machine running time of 22 minutes.



Figure C-1. X4 series Iowa loader operational shield

APPENDIX D

EVALUATION OF INSPECTION EQUIPMENT DESIGN "LESSONS LEARNED"

SUMMARY

MRC Corporation, Hunt Valley, MD, was awarded a contract to develop equipment for inspection of the M55 stab detonator. The required inspection is performed after the detonator is loaded and assembled by the Iowa multitool loader. Defects as defined by the scope of work include items such as incomplete crimp, exposed powder, missing closure disc, cracked or damaged housings, and overall dimensions.

The project was divided into two phases; Phase I--Develop a feasible concept and demonstrate the capability of the concept and Phase II--Design, fabricate, debug, test, and accept the prototype inspection equipment.

The results from the Phase I feasibility portion, resulted in an image evaluation system which uses a line scan charge coupled device (CCD) camera as the gaging system and an analog computer as the data processor.

During the debug and test portions of Phase II, problems were experienced with the mechanical system which transports the detonators to the inspection stations as well as the actual optical inspection system.

An amendment was made to the contract to effect a redesign of the mechanical and optical subsystems. The redesign effort included modification to the nests on the dial to provide accurate positioning of each nested detonator at the scanning stations and use of a rotating optical prism at the end view scan stations.

The result of the corrective redesign and modification was improved performance; however, the final evaluation was that the reliability and measurement accuracy of the system still did not lend itself to a usable on-line inspection system. In keeping with the preceding and the advances in technology which occurred since the inception of this program, it was decided that further expenditure of effort on this design is not warranted. Rather it was recommended that Lessons Learned be documented and alternative methods based upon current technologies presented for future programs.

This report is an evaluation of the design that was used in this development project. The intent of this evaluation is to identify problem areas that resulted in failure of the equipment to satisfy the requirements of the contract, and to present some alternative methods of providing the required inspection function using Lessons Learned in the original contract and current technology and equipment.

MECHANICAL DESIGN AND DEVELOPMENT

The design of the mechanism to transport the detonators to the scan stations (end-view scan and side-view scan) is a vertical dial (ferris wheel) 30 inches in diameter with 24 Vee-shaped nests in which the detonators are picked from a load point and transported to the work stations.

The vertical dial is rotated in 15-degree segments and locked in position with a pneumatically actuated tapered pin. In the original design the 24 Vee-shaped nests were machined into the dial. The Vee nests provide positioning and nesting of the detonators for end and side scanning rotation that is accomplished by an air motor. Contact between the detonators and the drive motor is made through a vacuum clutch.

Review and evaluation of the mechanical aspects has resulted in the prime conclusion that the wobble and chatter of the detonators as they are rotated by the vacuum clutch while contacting the surface of the Vee-shaped nest is a major problem of the original design and a cause for erroneous results from the optical scan system. Another basic conclusion is that the dial mechanism, as presented, cannot provide the precision required for detonator positioning accuracy.

Facts and sequential events bearing on these conclusions are as follows:

1. The dial as originally fabricated became warped during the machining process and the specified nest-to-nest and nest-to-work station accuracy was not achieved.

2. The dial was reworked by filleting the Vee's with weldment and grinding the surfaces of the notch. However, the transport and mechanical positioning of the detonators resulting from the reworked dial assembly continued to be a major problem and is apparent in the status reports 18 through 26 (14 Aug 81). The misalignment of the detonator with the scan system optics was the major setback to the initial debug and testing efforts.

3. An October 1982 redesign addressed the problem of mechanical precision of the dial and accurate positioning of each nest detonator at the end-view and side-view scan stations. The scope of work for the redesign included providing a new dial with a Vee nest in which detonators could be clamped, and a rotating dove prism used to eliminate rotating the detonator for the end-view scan station. The side-view scan station would still require that the detonator be rotated.

4. Subsequent testing and debugging of the rotating prism concept concluded that the rotational runout and optical aberrations of the "Dove Prism" system did not provide a stable image which could be evaluated reliably by the optical evaluation microprocessor. A concept to eliminate the Dove Prism and rotate the detonator in a redesigned nest with precision registration surfaces was later considered but never pursued due to termination of the program.

OPTICAL SYSTEM

There are two inspection stations on the machine where optical sensing is used to determine defective M55 detonator assemblies (i.e., malassembled closure disc, residue explosive composition, cracked housings, dimensions, etc.). The first of these stations inspects the crimped end of the detonator (end-view scan) and the second station inspects the cylindrical surface (side-view scan).

The heart of these inspection stations is a CCD video line scan camera. The line scan cameras selected for this project have a 512 x 1 pixel per scan resolution.

The image of the detonator being inspected is transmitted to the CCD sensors in the cameras by means of an off-the-shelf inspection lens available from the camera vendor (Fairchild).

During the contract extension for redesign, a special rotating prism was used to scan the end of the detonator radially at the end-view scan. Testing of this concept concluded that instability of the transmitted image, induced in part by the rotating prism, was a cause of inaccuracy in the evaluation of the line scan data. This problem could not be resolved, and the rotating prism concept was abandoned.

The surface of the detonator to be inspected was illuminated with a high intensity lamp. A lamp in the configuration of a ring was used to illuminate the detonator at the end-view station. The camera lens "looked through" the center of the ring. A lucite prism was used to transmit light from a high intensity lamp to the surface of the detonator at the side-view station.

The video line scan data are dependent on the reflected light from the subject. For this line scan inspection to accurately test for the cited flaws, it is essential that illumination of the area to be scanned comes from a light source which provides homogeneous light. Each pixel area must be illuminated by the same light intensity.

The status reports addressed the problem of illumination of the detonator especially at the side-view station. Illumination was cited as a problem throughout the project. Status Report 26 (14 Aug 81) states that the illumination using the plastic prism results in a "field that contains light and dark sectors." This report also recommends a new design to use fiber optic light transmission to illuminate the detonator. Fiber optic transmission to illuminate the detonator at the side-view station was included on the machine in January 1983. The January 26, 1983 Status Report states that "the new fiber optic coupler had more than enough light;" however, there is no evaluation of the uniformity of the illumination field. This report also states that "signal levels at the end-view station are still probably marginal pointing to barely adequate illumination levels."

Illumination of the detonator surface to be inspected is considered to be a high priority requirement for a successful inspection system. Mechanical wobble and chatter of the rotated detonator and nonuniformity in the illumination field on the surface to be inspected are considered the major causes of failure of the optical scan system. Either mechanical nonuniformity or inadequate illumination singularly are bad but together they present a situation which makes evaluation of other components in the optical scan system an impossible task.

Low intensity and nonuniform illumination are considered to be major problems and designs for future programs using optical scanners should place strong emphasis in the area of target illumination.

IMAGE PROCESSING SYSTEM

The purpose of the image processing system compares the scanning camera output to a standard signal pattern and produces a status signal (reject or accept).

The processor in the inspection module used a discreet circuit as the comparator and decision maker. This hardware approach is limited in memory capacity and restricts the scope of the algorithms in the processing philosophy. The result of this limitation is a very basic analysis of the video signal without the benefit of preconditioning the input video signal. The fixed discreet image processing circuit does not allow change to the image processing philosophy without major hardware modification.

An image processing system based on current microprocessor technology would allow the flexibility required for the experimental nature of the image evaluation. Changes could be made in software rather than hardware. The microprocessor system with its large memory capacity would allow an algorithm structure which would result in a highly detailed evaluation of the inputted video signal with the advantage of signal conditioning to reduce signal errors induced by aberrations in the optical components, nonuniformity of the illuminated field, and differences in sensitivity of the individual pixel elements.

CONTROL SYSTEM

The control system sequentially drives the functions of the dial and associated mechanisms in an automatic mode as cued by sensors and/or manual switches on the control panel. It provides a display of data, drives system status indicators on the control panel, and automatically updates the data and status displays at programmed intervals.

In the MRC system, the program is "burned" into read only memory (ROM) and requires a development system to effect a rewrite or change.

The major problem with this system is that it is overcomplicated for a machine to be used in a production plant environment and requires personnel with computer technology skills to operate it. A less complicated "user friendly" system such as a programmable controller could be used that would reduce testing and debugging costs because of the reduced level of technology required to operate the system.

CONCLUSIONS (CAUSE OF FAILURE)

1. The dial mechanism could not be manufactured to the precision required so that each nested detonator could be positioned accurately at the optical scan stations.
2. The detonator cannot be rotated while contacting the surface of the nest without wobble and chatter being induced.
3. Low intensity and nonuniform illumination of the detonator to be inspected resulted in scan line images that could not accurately and reliably be analyzed by the microprocessor.

NOTE: Conclusion 1, 2, and 3 result in an unstable scan-line signature and subsequent inaccurate data to the decision electronics.

4. The camera resolution (512 x 1 pixel) is marginal for the dimensional evaluations required and the flaws to be detected.
5. The dedicated, discreet circuit, image processor restricted the scope of the processing philosophy and algorithms. Modification of operating parameters would have required a major rebuild of hardware.
6. The control system is not flexible and the user program cannot be readily accessed or change. Computer technology skills are required to operate the system which creates potential burden in production plant environment.

RECOMMENDATIONS

1. The line scan inspection station should have a fixed detonator nest accurately aligned with the optical system. The nest should not be part of the transport mechanisms.
2. The nested detonator should not contact fixed surfaces when it is being rotated for scan inspection. The detonator must have freedom to rotate so that erratic motion will not be induced.
3. Side-view and end-view scan inspections should be incorporated in the same station. Two scan cameras and two illumination subsystems are required; however, transport problems will be lessened with only one location for both inspections. Both inspections should be performed simultaneously.
4. Detonators to be inspected should be illuminated with collimated light. Use of fiber optics to transmit the light from the source to the surface of the detonator should be further evaluated. High intensity incandescent or strobe lighting should also be evaluated.
5. The CCD video line scan camera should have a resolution of 1024 x 1 or 2048 x 1 pixel resolution. The lens system should be selected as dictated by physical position and lighting of the subject.
6. The control system and decision making electronics should be user friendly and should be capable of operation in a production plant environment without constant attendance by hi-tech computer science skills. State-of-the-art equipment which is standard and available "off the shelf" is preferred to custom designed and fabricated equipment or subsystems.

Programmable controllers and microprocessors are preferred over dedicated controllers and micros where the user program is burned in and cannot readily be changed.

A concept for a design which incorporate the features discussed in these recommendations is presented in figures D-1 and D-2.

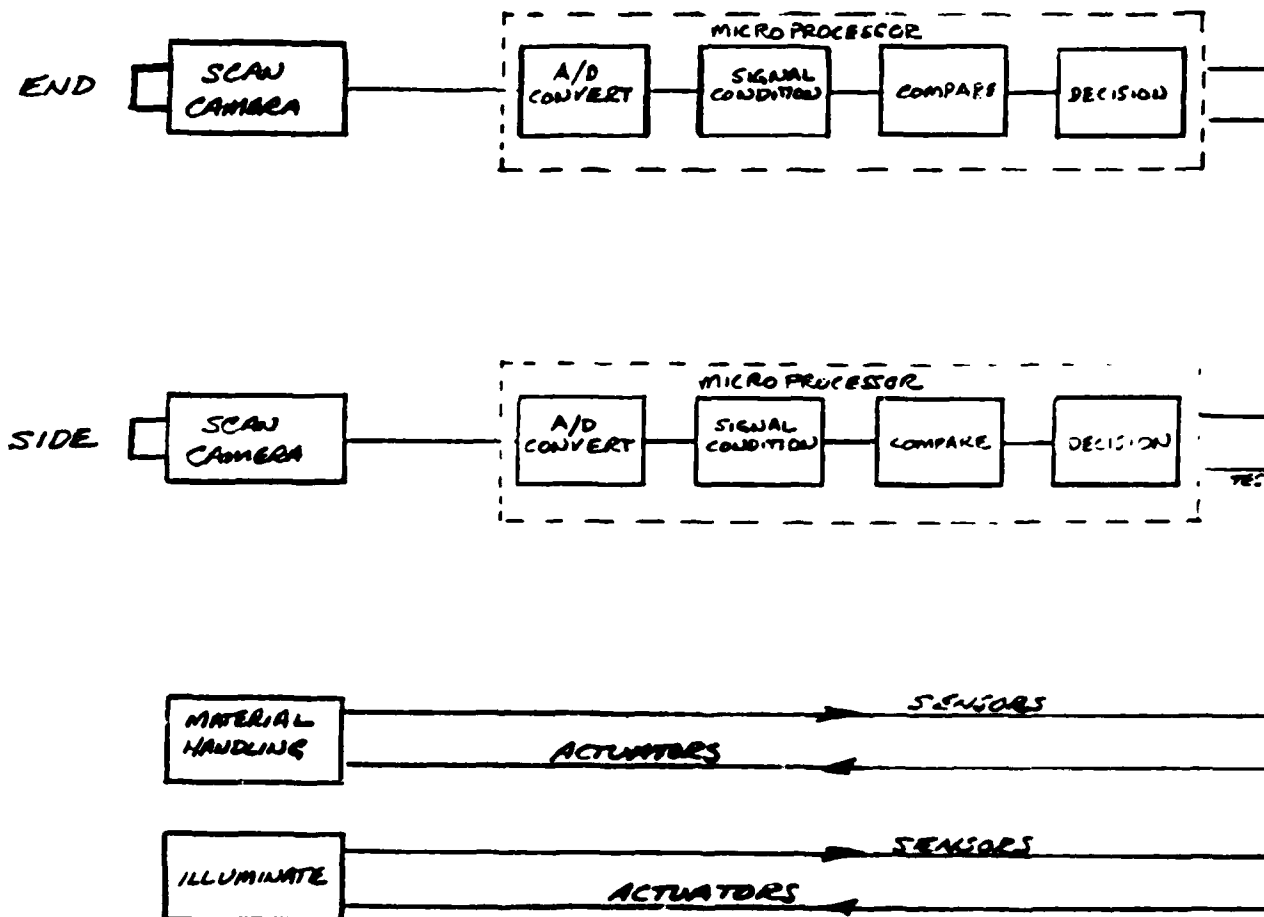
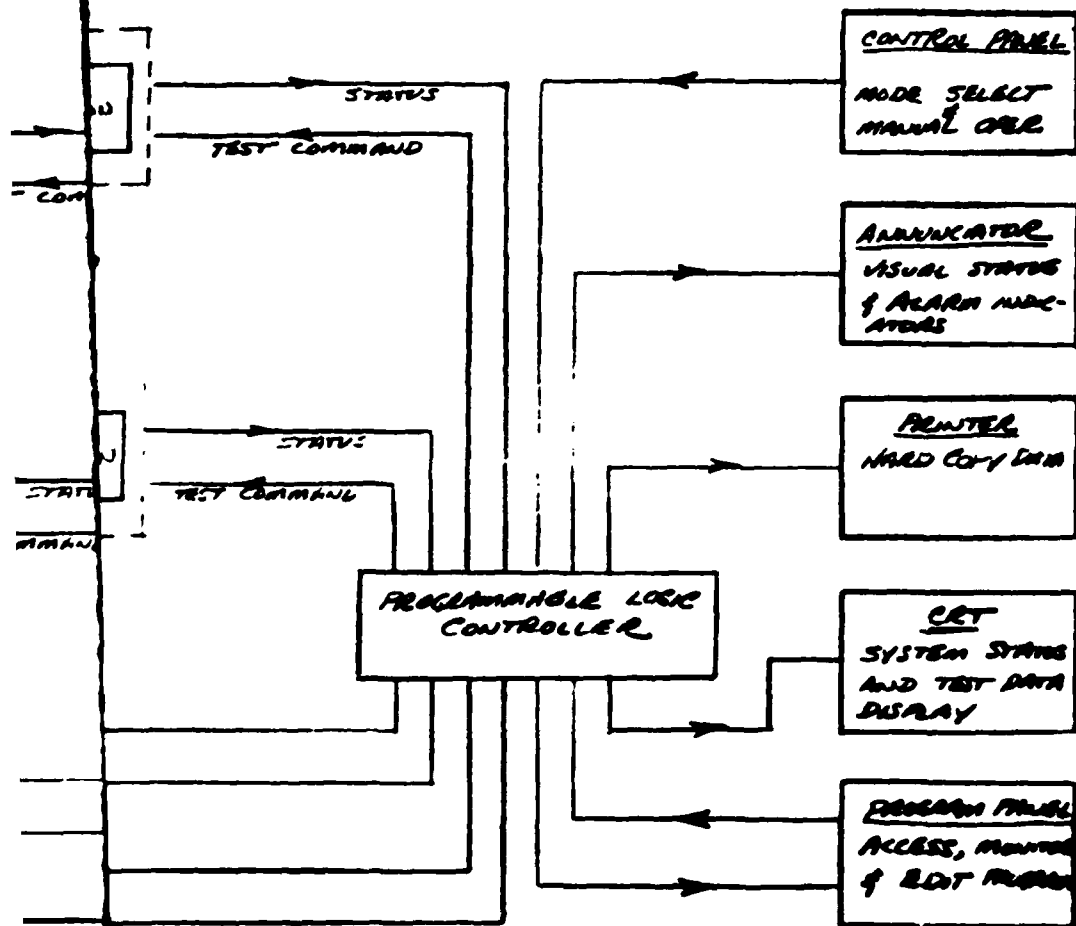


Figure D-1. Scan inspection system block diagram



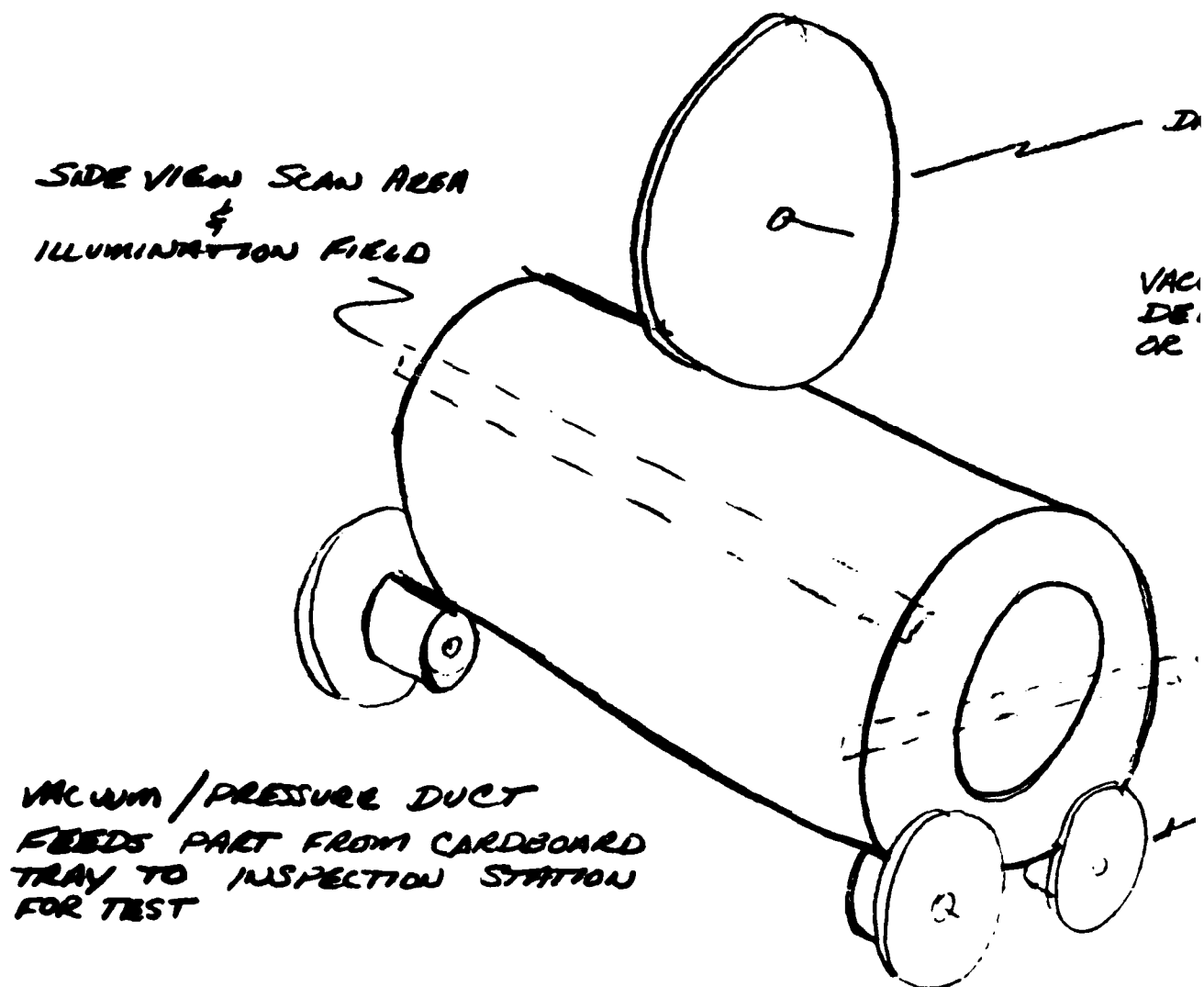


Figure D-2. Scan inspection system mechanical concept

DRIVE WHEEL INCREMENTALLY STRIPPED

VACUUM/PRESSURE DUCT
ITS DEPOSITS PART IN REJECT BIN
OR ACCEPT TRAY AFTER TEST

END VIEW SCAN AREA
&
ILLUMINATION FIELD

RUBBER IDLER 40.0

APPENDIX E

METERING ACCURACY IOWA BALL VS CHAMLEE

OBJECT

A comparison was made between the ability of the Chamlee loader and the Ball loader to dispense accurately both RD1333 lead azide and special purpose lead azide within ± 6 mg limits. This limit is derived from loading plant column height practices.

EXPERIMENTAL PROCEDURE

The powder dispensing devices known as the Ball loader (fig. E-1) and the Chamlee loader (fig. E-2) were bolted in turn to a heavy iron block. The block was necessary to minimize vibration which in preliminary trial led to erratic results.

An A. W. Hydon time delay relay operating on a 1.994 sec cycle triggered a Fisher transistor relay to operate a Allenair 3-way solenoid valve which provided 60 psi compressed air pulses to operate the loaders. A Kessler-Ellis electronic counter counted the pulses and stopped the dispensing at 150 increments (fig. E-3). Cycle times were 1 sec fill and 1 sec dispense or 2 sec total.

Prior to starting a 5-hr test, the loader was calibrated by first filling the hopper with 10 grams of lead azide. The loader was cycled 10 times and the resultant sample weighed. The loader was adjusted to about 51 mg over several successive trials, but obviously this preliminary mean was approximate and different for each loader/azide combination. After the start of a 5-hr test no further adjustments were made. The loaders (particularly the Ball loader) were cleaned between 5-hour tests because a heavy deposit of lead and lead azide built up on the ball during the test.

Prior to use and to avoid errors due to a poorly fitting seal, the ball loader funnel bearing was sent to Iowa AAP and ground and polished to fit the ball using their standard procedure.

During the summer, the humidity and temperature were maintained within safe operating conditions by the building air-conditioning. As the weather cooled in the fall, the humidity in the hood was kept to at least 50% by introduction of steam into the atmosphere. The temperature ranged from 64°F to 83°F (18° to 28°C) while humidities went from 52% to 90%.

The lead azide was metered at a rate of 30 increments per minute over a period of 5 hours to evaluate one loader's performance with each lead azide. The 5-hr period was broken down into sixty 5-minute runs of 150 increments. At a random time during each 5-minute run, a single increment was caught separately. The individual increment was weighed and identified as the "individual sample." The weight of the remaining 149 increments was added to the individual sample and divided by 150 to obtain the "cumulative average sample." The samples of azide were returned to the hopper and the same 10 grams of each type of lead azide was used repeatedly in both loader tests.

The two lots of lead azide used were Special Purpose lot JA4-61 and RD-1333 lot OMC2-2. The Ball loader was numbered 14. The Chamlee loader metal body was

numbered E4190-E. The critical metering hole diameters were determined by improvising go/no-go gages from the drill rod. From this it was determined that the following dimensions existed. It was not possible to measure closely enough to detect wear (if any occurred). Based on the bulk densities of the explosives (1.49 g/cm^3 for SPLA and 1.34 g/cm^3 for RD-1333), the volumes were estimated.

<u>Loader</u>	<u>Volume, cm^3</u>	<u>Hole diameter, in.</u>	<u>Specified</u>
Chamlee	0.035	0.105	0.105 E4190-N-13
Ball	0.038	0.157	NA

RESULTS

In the following tabulated results the difference between means are not significant. The deviation and spread differences are the significant values to be used in evaluating the performance of the loaders.

<u>Loader type</u>	<u>Azide type</u>	<u>Individual samples, mg</u>			<u>Cumulative samples, mg</u>		
		<u>Mean</u>	<u>Deviation</u>	<u>Spread</u>	<u>Mean</u>	<u>Deviation</u>	<u>Spread</u>
Chamlee	Special Purpose (Lot JA 4-61)	50.4	1.81	8.8	49.7	1.19	4.3
Chamlee	RD1333 (Lot OMC 2-2)	50.0	2.42	8.0	50.2	1.68	7.1
Ball	Special Purpose (Lot JA 4-61)	54.9*	2.56	10.2	54.6	2.53	12.4
Ball	RD1333	52.7	1.59	8.5	53.3	0.88	3.9

*Average of 59 due to weighing error.

The trends and changes of pattern of delivery can be visualized by reference to figures E-4 through E-7. Plots for the cumulative samples (figs. E-4 and E-5) and for individual samples (figs. E-6 and E-7) for RD1333 and Special Purpose clearly show the increase in the amount delivered by the Ball loader as the 5-hr test progressed.

To determine if the results of the individual samples were significantly different, the differences between the lowest deviation (which was 1.59 mg for RD1333 dispensed by the Ball loader) and the other deviations were tested for significance according to AMCP 706-114 Experimental Statistics, Section 1, Chapter 4, with the following results:

<u>Loader/azide</u>	<u>Standard deviation</u>	<u>Significant difference at confidence level</u>	
		<u>95%</u>	<u>99%</u>
Chamlee/Special Purpose	1.81	No	No
Chamlee/RD	2.42	Yes	Yes
Ball/Special Purpose	2.56	Yes	Yes

To comply with the ± 6 -mg goal, a standard deviation of 2.0 would be needed for the individual samples and a deviation of 0.2 for the cumulative samples. Neither loaders met the individual sample limits reliably and deviation for the cumulative samples were substantially higher than predicted. At this point no explanation can be given for this seeming anomaly.

The Chamlee can be adjusted for the amount delivered remotely without stopping and shows only random deviation from the mean. The Ball loader has to be stopped to adjust the quantity delivered. It showed a progressive increase in quantity delivered because of the buildup on a film of lead (actually a mix of lead azide and its decomposition products all the way down to pure lead) (fig. E-8). It is understood that this film is removed in production at the end of the 8-hr shift and the amount delivered adjusted progressively throughout the shift. The film noticeably altered the output of the Ball loader during the first 2 or 3 hours of these tests. In fact, it caused the sealing gasket to lift up and allowed small quantities of azide to be dispensed on the backstroke.

CONCLUSIONS

1. Neither the Chamlee nor the Ball dispenser met the goal of 51 ± 6 mg consistently.
2. Results of tests showed no significant differences between the two techniques as far as accuracy is concerned.
3. The Ball results in successive increases in increment weight with time; the Chamlee results in a random spread with time.

RECOMMENDATIONS

In view of the insignificant differences in performance (spread and deviation) between the two techniques, the advantages offered by the Chamlee with respect to "on-the-fly" adjustment, lower blow rate, and no requirement for frequent cleaning would appear to make the Chamlee the preferred technique.

APPENDIX F
DETONATOR SEAL AND DRY SYSTEM

INITIAL LACQUER DISPENSING EFFORT - SINGLE SHOT DISPENSOR

One of the proposed improvements for the X-4 loader was to develop an improved M55 detonator paint system. As proposed, this system will consist of the following:

1. A conveyor to transport M55 packs to a painting machine
2. A painting machine which will locate the pack and incorporate a dispensing unit
3. An oven used to dry the painted detonators

This system is considered to be very low risk with exception of the dispensing unit.

A pinch tube type dispenser has initially been tested. This unit dispenses one drop at a time. The production version would consist of a 5x10 matrix and dispense 50 simultaneous drops.

This study consisted of observing the detonator paint machine over a 2-day period. The machine was observed at 15-min intervals to determine possible problems or inconsistencies that might occur (table F-1). At approximately 30-min intervals, data were collected to determine the consistency of the paint drops. The detonator painter was left running overnight during the 2-day period to determine possible wear on the machine from continuous operation.

On the first test day, the painter was observed from 9:30 A.M. until 3:45 P.M. Six data blocks that were collected throughout the day are shown in figure F-1. There are only minor fluctuations between the blocks collected during a 6-hr period at 10 sec/cycle. During the day, no problems with the painter were observed. From 3:45 P.M. until 8:30 A.M. the next morning, the painter was left operating without being observed. At 8:30 A.M., the painter was still running but leakage was noticed around the fitting connected to the hose fixture. The leakage occurred because the fitting had become loose. Data was collected at 8:30 A.M. (fig. F-2). The paint drops were much larger than the previous day's collection. This inconsistency apparently occurred because of wear on the hose and leakage around the fitting.

After data were collected, the hose was removed from the fixture to determine wear from operating the detonator painter for 24 hr continuously. The protective housing surrounding the hose was completely worn through. The hose was not leaking, but it was badly worn. After running for 24 hr, approximately 20% of the paint in the reservoir had been used. Once the observations were made, the hose was cut off above the damaged area and the protective housing was replaced.

On the second test day, the painter was observed from 9:30 A.M. until 2:15 P.M. At 10:45 A.M., the number of seconds between cycles was changed from 10 to 15. The painter was shut down from 11:30 A.M. until 1:00 P.M. to simulate a lunch break. When the painter was restarted at 1:00 P.M., the needle was clogged with dried paint. By increasing the reservoir pressure and switching the painter to manual mode, the dried paint was removed quite easily.

At 2:15 P.M., a test was conducted to determine at what distance a detonator could be from the needle and still receive a paint drop. The maximum distance was found to be approximately 0.045 in. However, the detonators would not receive drops consistently at that distance. Consistency was found at 0.030 in.

At 2:30 P.M., the existing needle was replaced with a smaller one. From 2:30 P.M. until 9:30 A.M. the next morning, the painter was operating without being observed. At 9:30 A.M., the painter was still operating but no paint was being released. The clog was caused because of the smaller needle and the increased cycling time used. Once again, the hose was removed from the fixture to determine wear. As before, the protective housing was worn through where the valve made contact but was still usable.

After observing the detonator painter over a 2-day period, some general conclusions were made:

1. The painter will cycle at consistent intervals for at least a 24-hr period
2. The paint drop size appears to remain consistent for 8 to 16 hours
3. The hose and protective housing will have to be replaced after 8 to 16 hours of continuous use
4. There are several variables involved in determining over what period of time the needle will clog; the most important being needle size and cycle time
5. When a needle becomes clogged, there is a very quick and simple method of correcting this; switching the painter to manual mode and increasing the reservoir pressure to 15 or 20 psi
6. The amount of paint used in a day's time is minimal; therefore, refilling the reservoir should cause no problems
7. With the number of adjustments available on the painter, the drop size needed can be obtained using several different sized needles

The general conclusions mentioned have been made after a minimal observation period. Some recommendations on additional testing are as follows:

1. Experiment with different needle diameters and lengths to obtain proper drop size needed
2. Experiment with various hose diameters without using a needle
3. Experiment with various types of protective housing and hose materials to determine what provides optimal wear
4. Experiment with the intent of easing wear on hose by decreasing shutoff force and/or reservoir pressure

5. Experiment with cycling time to find minimum and maximum possible without clogging, with respect to different needle sizes

APPENDIX G
IMPROVED ASPIRATION SYSTEM

COST COMPARISON ANALYSIS

A cost study was performed to determine potential savings by using steam ejection or a vacuum pump system instead of air operated ejection for Iowa loader aspiration and vacuum drying.

This comparison (table G-1) was based on the use of two 1000 hp, 5100 I.C.F.M. air compressors for the compressed air supply, while the aspiration equipment was to consist of 180 penberthy #22A ejectors for the Iowa loaders and 52 penberthy #5A ejectors for the process barricades. The vacuum pump operating cost was based on electrical cost only, as service liquid and maintenance costs were unknown.

Total air consumption of the aspirators was found to be 9112 C.F.M. Therefore, using a vacuum pump system for these two operations would result in considerable downsizing of air compressors and related equipment, since only 1000 C.F.M. (approx) would then be required.

It was determined that the vacuum pump system was the cheapest alternative, with air operated aspiration next in line, although considerably more expensive. The use of steam as the operating media for the penberthy ejectors was actually found to be the most expensive of all three.

While several costs were not taken into account in determining the operating cost of the vacuum pump, its cost was considerably less than the others, so that the addition of the unknown costs should not change the order of the finding; the vacuum pump should remain the cheapest alternative.

Although the study was based on only one vacuum pump, it would undoubtedly be more convenient to use two: one for the Iowa loaders and one for the process barricade. These two pumps would not need to be the same size, of course.

TEST OF LIQUID RING VACUUM SYSTEM WITH INERT MATERIAL

Prior to introduction of explosives to the vacuum system, a test was performed with the inert material lead sulfate ($PbSO_4$). The primary purpose was to obtain an indication of the quantity of explosives that will reach the liquid ring vacuum pump. The second objective was to determine which of three screens will do the best job of filtering. The results indicate a small amount of carry-over to the vacuum pump, and the number 25 mesh screen filtered the most material. (See table G-2 for a tabulation of the results.)

The screen that produced the best filtering in the large chamber was the #25 mesh with 1096 ppm of lead sulfate, the #18 was second, and the #50 produced the worst results.

The medium and small chambers have no screens to effect their filtering capabilities. The only three variables that could influence the filtering was the air flow, amount of lead sulfate introduced into the system, and the amount of lead sulfate filtered in the previous chambers. The air flow and the amount of lead sulfate introduced were unchanged for each test. Therefore, the only

influencing factor is the amount of lead sulfate filtered in the previous chambers. It would be expected that the more that is filtered in the first chamber, the less there is to filter in the following chambers. The results are just the opposite in that the more that is filtered in the first chamber, the more is filtered in the following chambers.

The analysis of the vacuum pump tank sample shows that before anything was introduced to the system, lead sulfate was present. As the lead sulfate was filtered, the ppm in the vacuum tank slightly increased. After the vacuum line was flushed, the vacuum pump tank showed an increase in lead sulfate present (table G-2).

The results of the inert test are somewhat questionable. But since the analysis shows that the quantities in the vacuum tank samples are minute, explosives should be introduced to the system. The largest quantities were filtered with the #25 mesh screen so this one should be used when explosives are added to the system.

Table G-1. Approximate operating cost summary

	Penberthy ejectors				Vacuum pump system	
	Air operated		Steam operated		Total suction (CFM)	Total operating cost (\$/hr)
	Total air consumption (CFM)	Total operating cost (\$/hr)	Total steam consumption (lb/min)	Total operating cost (\$/hr)		
Iowa loaders 180 - #22A ejectors	3600	15	180.0	30	504	
Process harricades 52 - #5A ejectors	5512	23	275.6	45	208	0.90

Vacuum pump system based on 49 hp, 765 CFM, SIHI liquid ring vacuum pump, compressed air \$0.07/1000 ft³.
 Steam cost used was \$2.74/1000 lb.
 Electricity \$0.0219/kw-hr.

Table G-2. Amounts of lead sulfate in sample water of the X4 vacuum system*

	<u>Before tests</u>	<u>#50 mesh (100 g)</u>	<u>#25 mesh (100 g)</u>	<u>#18 mesh (100 g)</u>	<u>After 5 gal. flush</u>
LRVP	1.8	1.3	2	3.0	9.8
Small chamber		40.2	81.0	122.4	
Medium chamber		123.0	513.0	260.0	
Large chamber		586.0	1096.0	895.0	

* All quantities in parts per minute (ppm).

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